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Hanford Site National Environmental Policy Act (NEPA) Characterization

C. E. Cushing, Editor

September 1990

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
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HANFORD SITE NATIONAL ENVIRONMENTAL POLICY ACT (NEPA) CHARACTERIZATION

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Pacific Northwest Laboratory
Richland, Washington 99352

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FOREWORD

This document describes the Hanford Site environment (Chapter 4.0) and contains data in Chapters 5.0 and 6.0 that will assist users in the preparation of National Environmental Policy Act- (NEPA-) related documents.

Many NEPA compliance documents have been prepared and are being prepared by site contractors for the U.S. Department of Energy (DOE), and examination of these documents reveals inconsistencies in the amount of detail presented and the method of presentation. Thus, it seemed necessary to prepare a consistent description of the Hanford Site environment to be used in preparing Chapter 4.0 of environmental impact statements and other site-related NEPA documentation. The material in Chapter 5.0 is a guide to the models used, including critical assumptions incorporated in these models in previous Hanford NEPA documents. The user will have to select those models appropriate for the proposed action. Chapter 6.0 is essentially a definitive NEPA Chapter 6.0, which describes the applicable laws, regulations, and DOE and state orders.

In this document, a complete description of the environment is presented in Chapter 4.0 without extensive tabular data. For these data, sources are provided. Most subjects are divided into a general description of the characteristics of the Hanford Site, followed by site-specific information where it is available on the 100, 200, 300, and other Areas. This division will allow a person requiring information to go immediately to those sections of particular interest. However, site-specific information on each of these separate areas is not always complete or available. In this case, the general Hanford Site description should be used.

To enhance the usability of the document, a copy of the entire text is available on an IBM PC diskette in WordPerfect 5.0 upon request to C. E. Cushing at (509) 376-9670. The figures can be obtained by contacting Dan Foley in the Boeing Company Services Richland (BCSR) Graphics Department, located in the Pacific Northwest Laboratory Research Operations Building.

Personnel who prepared the various sections of this document and who should be contacted with questions are:

Document Editor	C. E. Cushing	376-9670
Climate/Meteorology	D. J. Hoitink	376-8864
Air Quality	D. L. Hadley	375-3708
Geology/Hydrology	R. W. Wallace	376-8308
Ecology	C. E. Cushing	376-9670
Historical, Archeological, and Cultural Resources	J. C. Chatters	376-9469
Socioeconomics	S. J. Marsh	376-1939
	A. G. Thurman	376-4118
Noise	T. M. Poston	376-5678
Models Used to Estimate Environmental Impacts (and Critical Assumptions for Models)	D. A. Baker	375-3809
Statutory and Regulatory Requirements	E. B. Moore	376-1089

C. E. Cushing, Editor

CONTENTS

FIGURES

TABLES

4.0 AFFECTED ENVIRONMENT

The U.S. Department of Energy's Hanford Site lies within the semiarid Pasco Basin of the Columbia Plateau in southeastern Washington State (Figure 4.0-1). The Hanford Site occupies an area of about 1450 km^2 (~560 mi^2) north of the confluence of the Snake and Yakima rivers with the Columbia River. The Hanford Site is about 50 km (30 mi) north to south and 40 km (24 mi) east to west. This land, with restricted public access, provides a buffer for the smaller areas currently used for production of nuclear materials, waste storage, and waste disposal; only about 6% of the land area has been disturbed and is actively used. The Columbia River flows through the northern part of the Hanford Site, and turning south, it forms part of its eastern boundary. The Yakima River runs along part of the southern boundary and joins the Columbia River below the city of Richland, which bounds the Hanford Site on the southeast. Rattlesnake Mountain, the Yakima Ridge, and the Umtanum Ridge form the southwestern and western boundary. The Saddle Mountains form the northern boundary of the Hanford Site. Two small east-west ridges, Gable Butte and Gable Mountain, rise above the plateau of the central part of the Hanford Site. Adjoining lands to the west, north, and east are principally range and agricultural land (Figure 4.0-2). The cities of Richland, Kennewick, and Pasco (Tri-Cities) constitute the nearest population center and are located southeast of the Hanford Site.

4.1 CLIMATE AND METEOROLOGY

The Hanford Site is located in a semiarid region of southeastern Washington State. The Cascade Mountains beyond Yakima to the west greatly influence the climate of the Hanford area because this range has a rain shadow effect and also serves as a source of cold air drainage, which has a considerable effect on the wind regime on the Hanford Site.

Climatological data are available for the Hanford Meteorological Station (HMS), which is located between the 200-East and 200-West Areas. Data have been collected at this location since 1945. Temperature and precipitation data are also available from nearby locations for the period 1912 through

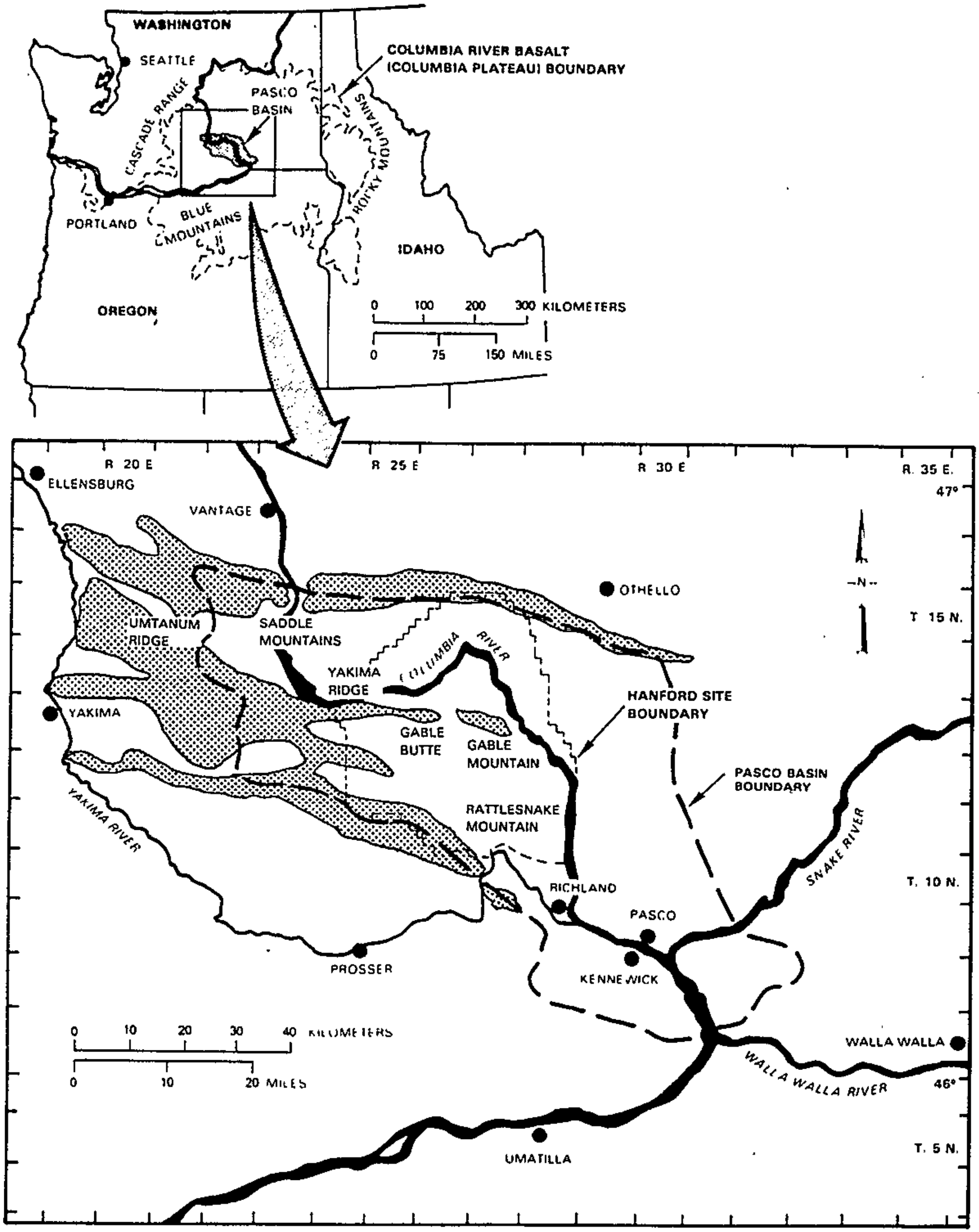


FIGURE 4.0-1. Hanford Site and Environs (stippled areas denote basalt outcroppings)

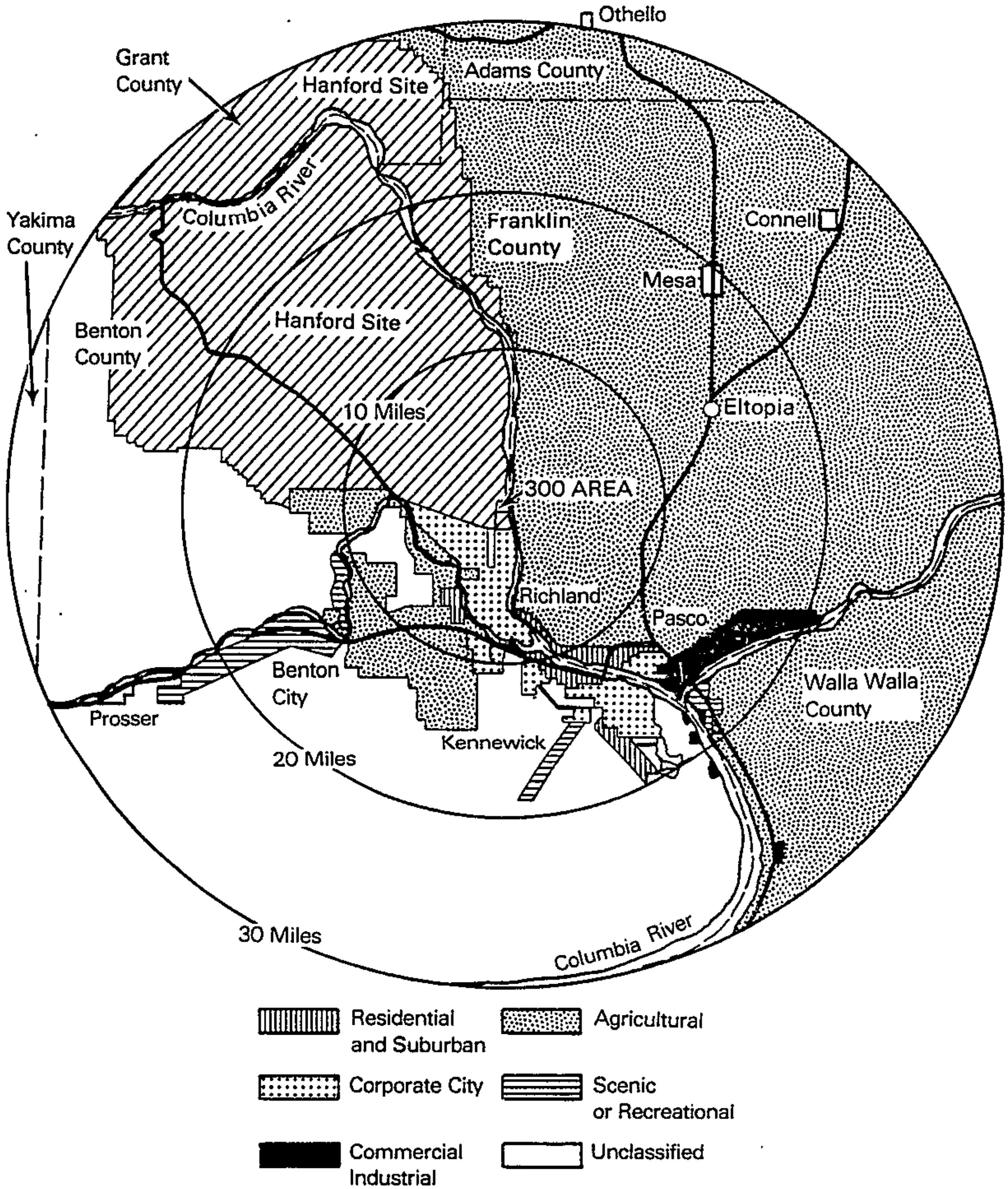


FIGURE 4.0-2. Zoning Status of Area Surrounding the Hanford Site

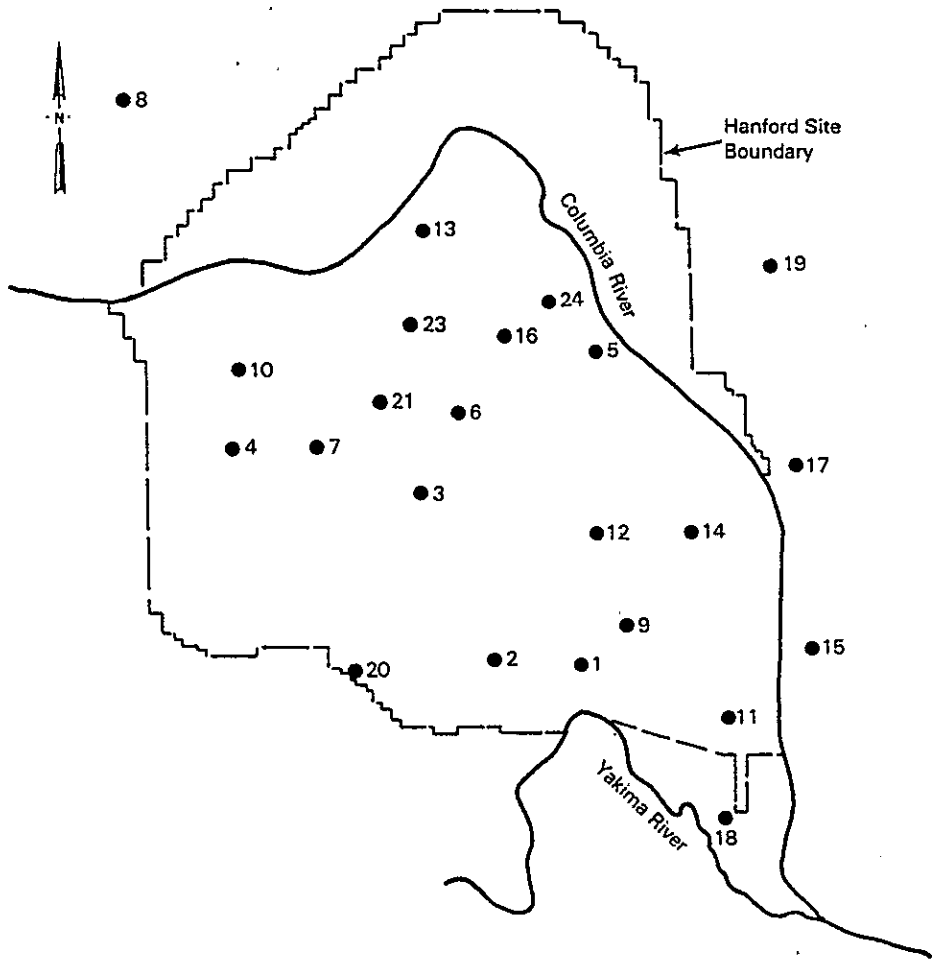
1943. A summary of these data through 1980 has been published by Stone et al. (1983). Data from the HMS are representative of the general climatic conditions for the region and describe the specific climate of the 200-Area Plateau. There are local variations in the topography of the Hanford Site that may cause some aspects of climate at portions of the Hanford Site to differ significantly from those of the HMS. For example, winds near the Columbia River are different than those at the HMS. Similarly, precipitation along the slopes of the Rattlesnake Hills differs climatically from that at the HMS.

4.1.1 Wind

Wind data are collected at the HMS at the surface [2.1 m (~7 ft) above the ground] and at the 15.2-, 30.5-, 61.0-, 91.4-, and 121.9-m levels of a 125-m tower. Three 60-m towers, with wind measuring instrumentation at the 10-, 25-, and 60-m levels, are located at the primary operating areas (300, 400, and 100-N Areas). In addition, wind instruments on twenty-one 9.1-m towers distributed on and around the Hanford Site (Figure 4.1-1) provide supplementary data for defining wind patterns.

Prevailing wind directions on the 200-Area Plateau are from the northwest in all months of the year (Figure 4.1-2). Secondary maxima occur for southwesterly winds. Summaries of wind direction indicate that winds from the northwest quadrant occur most often during the winter and summer. During the spring and fall, the frequency of southwesterly winds increases with a corresponding decrease in northwest flow. Winds blowing from other directions (e.g., northeast) display minimal variation from month to month.

Monthly and annual joint frequency distributions of wind direction versus wind speed for the HMS are given in Stone et al. (1983). Monthly average wind speeds are lowest during the winter months, averaging 10 to 11 km/h, and highest during the summer, averaging 14 to 16 km/h. Wind speeds that are well above average are usually associated with southwesterly winds. However, the summertime drainage winds are generally northwesterly and frequently reach 50 km/h (30 mi/h). These winds are most prevalent over the northern portion of the Hanford Site.



Station No.	Station Name	Station No.	Station Name
1	Prosser Barricade	14	WPPSS
2	EOC	15	Franklin County
3	Army Loop Road	16	Gable Mountain
4	Rattlesnake Springs	17	Ringold
5	Edna	18	Richland Arpt
6	200-East	19	Sagehill
7	200-West (BWIP)	20	Rattlesnake Mtn
8	Wahluke Slope	21	HMS (121.9-m)
9	FFTF (60-m)	22	Pasco Arpt
10	Yakima Barricade	23	Gable West
11	300-Area (60-m)	24	100-F
12	Wye Barricade	25	Vernita
13	100-N (60-m)		

NOTE: All network stations are 9.1 m (~30 ft) unless otherwise indicated.

FIGURE 4.1-1. Hanford Site Wind Monitoring Network

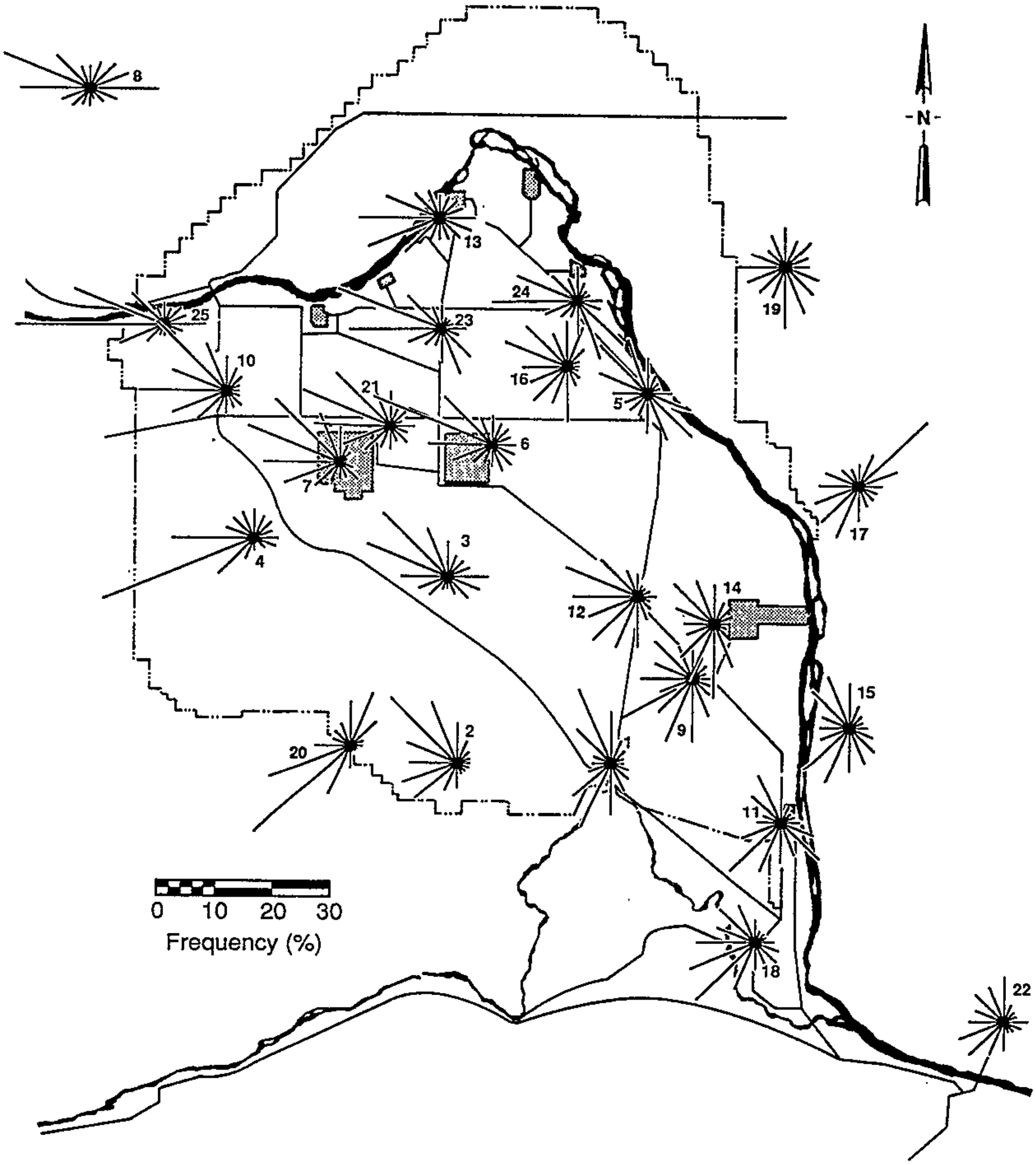


FIGURE 4.1-2. Wind Roses for the Hanford Telemetry Network, 1979-1988. The point of each rose represents the directions from which the winds come.

4.1.2 Temperature and Humidity

Temperature measurements are made at the 0.9-, 9.1-, 15.2-, 30.5-, 61.0-, 76.2-, 91.4-, and 121.9-m levels of the 125-m (400-ft) tower at the HMS. As of May 1987, temperatures are also measured at the 2-m level on the twenty-one 9.1-m towers located on and around the Hanford Site. The three 60-m towers have temperature-measuring instrumentation at the 2-, 10-, and 60-m levels. The temperature data from the 9.1- and 60-m towers are telemetered to the HMS.

Diurnal and monthly averages and extremes of temperature, dew point, and humidity are contained in Stone et al. (1983). Ranges of daily maximum and minimum temperatures vary from normal maxima of 2°C (36°F) in early January to 35°C (95°F) in late July. There are, on the average, 55 days during the summer months with maximum temperatures greater than or equal to 32°C and 13 days with maxima greater than or equal to 38°C. From mid-November through mid-March, minimum temperatures average less than or equal to 0°C with the minima in early January averaging -6°C. During the winter, there are an average of 4 days with minimum temperatures less than or equal to -18°C; however, only about one winter in two experiences such temperatures. The record maximum temperature is 46°C, and the record minimum temperature is -32.8°C. For the period 1912 through 1980, the average monthly temperatures range from a low of -1.5°C in January to a high of 24.7°C in July. During the winter, the highest monthly average temperature at the HMS was 6.9°C, and the record lowest was -5.9°C; both having occurred during February. During the summer, the record maximum monthly average temperature was 27.9°C (in July), and the record lowest was 17.2°C (in June).

Relative humidity/dew point temperature measurements are made at the HMS and at the three 60-m (200-ft) tower locations. The annual average relative humidity at the HMS is 54%. It is highest during the winter months, averaging about 75%, and lowest during the summer, averaging about 35%. Wet bulb temperatures greater than 24°C had not been observed at the HMS before 1975; however, on July 8, 9, and 10 of that year, there were seven hourly observations with wet bulb temperatures greater than or equal to 24°C.

4.1.3 Precipitation

Precipitation measurements have been made at the HMS since 1945. Average annual precipitation at the HMS is 16 cm (6.3 in). Most of the precipitation occurs during the winter with nearly half of the annual amount occurring in the months of November through February. Days with greater than 1.3 cm precipitation occur less than 1% of the year. Rainfall intensities of 1.3 cm/h persisting for 1 hour are expected once every 10 years. Rainfall intensities of 2.5 cm/h for 1 hour are expected only once every 500 years. Winter monthly average snowfall ranges from 0.8 cm in March to 13.5 cm in January. The record snowfall of 62 cm occurred in February 1916. Snowfall accounts for about 38% of all precipitation during the months of December through February.

In the spring of 1987, precipitation measurements for four other locations (Rattlesnake Mountain, Richland Airport, Rattlesnake Springs, and Yakima Barricade) were added to the meteorological measurement system. Climatological precipitation measurements have also been made on the Arid Lands Ecology Reserve on the western slope of the Rattlesnake Hills (Stone et al. 1983).

4.1.4 Fog and Visibility

Fog has been recorded during every month of the year at the HMS; however, 95% of the occurrences are during the months of November through February, with less than 1% during the months of April through September (Table 4.1-1). The average number of days per year with fog (visibility less than or equal to 9.6 km or 6 mi) is 45, and with dense fog (visibility less than or equal to 0.4 km or 0.25 mi), 24. The greatest number of days with fog was 84 days in 1985-1986 and the least 22 in 1948-1949; the greatest number of

TABLE 4.1-1. Number of Days with Fog by Season

Category	Winter	Spring	Summer	Autumn	Total
Fog	31	2	≤1/2	12	45
Dense fog	17	1	≤1/2	6	24

days with dense fog was 42 days in 1950-1951, and the least, 9 days in 1948-1949. The greatest persistence of fog was 114 hours (December 1985), and the greatest persistence of dense fog was 47 hours (December 1957).

Other phenomena causing restrictions to visibility (i.e., visibility less than or equal to 9.6 km) include dust, blowing dust, and smoke. The number of such days is small, with an average of 5 days per year with dust or blowing dust, and less than 1 day per year with reduced visibility due to smoke.

4.1.5 Severe Weather

High winds are also associated with thunderstorms. The average occurrence of thunderstorms is 10 per year. They are most frequent during the summer; however, they have occurred in each month. The average winds during thunderstorms do not come from any specific direction. Estimates of the extreme winds, based on peak gusts observed from 1945 through 1980, are given in Stone et al. (1983) and are shown in Table 4.1-2. Using the National Weather Service criteria for classifying a thunderstorm as "severe" (i.e., hail with a diameter equal to or greater than 20 mm or wind gusts of 93 km/h or greater), only 1.9% of all thunderstorm events observed at the HMS have been "severe" storms, and all met the criteria based on wind gusts.

Tornadoes are infrequent and generally small in the northwest portion of the United States. Grazulis (1984) lists no violent tornadoes for the region surrounding Hanford (DOE 1987). The HMS climatological summary (Stone et al. 1983) and the National Severe Storms Forecast Center (NSSFC) data base list

TABLE 4.1-2. Estimates of Extreme Winds at Hanford Site

Return Period, yr	Peak Gusts, km/h: 15.2 m Above Ground	Peak Gusts, km/h: 61 m Above Ground
2	97	109
10	114	129
100	137	151
1000	159	175

22 separate tornado occurrences within 161 km of the Hanford Site from 1916 through August 1982. Two additional tornadoes have been reported since August 1982.

Using the information in the preceding paragraph and the statistics published in Ramsdell and Andrews (1986) for the 5° block centered at 117.5° west longitude and 47.5° north latitude (the area in which the Hanford Site is located), the expected path length of a tornado on the Hanford Site is 7.6 km, the expected width is 95 m, and the expected area is about 1.5 km^2. Also from Ramsdell and Andrews (1986), the estimated probability of a tornado striking a point at Hanford is 9.6×10^{-6}/yr. The probabilities of extreme winds associated with tornadoes striking a point can be estimated using the distribution of tornado intensities for the region. These probability estimates are given in Table 4.1-3.

4.1.6 Atmospheric Dispersion

Atmospheric dispersion is a function of wind speed, duration and direction of wind, atmospheric stability, and mixing depth. Dispersion conditions are generally good if winds are moderate to strong, the atmosphere is of neutral or unstable stratification, and there is a deep mixing layer. Good dispersion conditions associated with neutral and unstable stratification exist about 57% of the time during the summer. Less favorable dispersion conditions may occur when the wind speed is light and the mixing layer is shallow. These conditions are most common during the winter when moderately to extremely stable stratification exists about 66% of the time. Less

TABLE 4.1-3. Estimate of the Probability of Extreme Winds Associated with Tornadoes Striking a Point at Hanford (Ramsdell and Andrews 1986)

Wind Speed, km/h	Probability per Year
100	2.6×10^{-6}
200	6.5×10^{-7}
300	1.6×10^{-7}
400	3.9×10^{-8}

favorable conditions also occur periodically for surface and low-level releases in all seasons from about sunset to about an hour after sunrise as a result of ground-based temperature inversions and shallow mixing layers. Mixing-layer thicknesses have been estimated at the HMS using remote sensors. The variations in mixing layer described previously are summarized in Table 4.1-4.

Occasionally there are extended periods of poor dispersion conditions that are associated with stagnant air in stationary high-pressure systems that occur primarily during the winter months. Stone et al. (1972) estimated the probability of extended periods of poor dispersion conditions. The probability of an inversion period extending more than 12 hours varies from a low of about 10% in May and June to a high of about 64% in September and October. These probabilities decrease rapidly for durations of greater than 12 hours. Table 4.1-5 summarizes the probabilities associated with extended surface-based inversions.

TABLE 4.1-4. Percent Frequency of Occurrence of Mixing-Layer Thickness by Season and Time of Day

Mixing Layer, m	Winter Night	Winter Day	Summer Night	Summer Day
Less than 250	65.7	35.0	48.5	1.2
250-500	24.7	39.8	37.1	9.0
Greater than 500	9.6	25.2	14.4	89.9

TABLE 4.1-5. Percent Probabilities for Extended Periods of Surface-Based Inversions

Months	Inversion Duration 12 h	24 h	48 h
January-February	54.0	2.5	0.28
March-April	50.0	<0.1	<0.1
May-June	10.0	<0.1	<0.1
July-August	18.0	<0.1	<0.1
September-October	64.0	0.11	<0.1
November-December	50.0	1.2	0.13

Annual average atmospheric diffusion factors (χ/Q') have been computed at the Skagit-Hanford Site, the 200-East Area, and the 400 Area using 1983 through 1987 meteorological data. These diffusion factors are presented in Tables 4.1-6 through 4.1-9 as a function of direction and distance from the facility. Table 4.1-6 for the Skagit-Hanford Site and Table 4.1-9 for the 400 Area are for ground-level releases. For the 200-East Area, diffusion factor tables are presented for both elevated (Table 4.1-7) and ground-level (Table 4.1-8) releases. An effective stack height of 89 m (292 ft) has been assumed for elevated releases in Table 4.1-7, based on an actual stack height of 60 m (197 ft) and a typical plume rise of 28 m (92 ft).

4.1.7 Air Quality

National ambient air quality standards (NAAQS) have been set by the U.S. Environmental Protection Agency (EPA), as mandated in the 1970 Clean Air Act. "Ambient air" is defined (NRC 1982) as "that portion of the atmosphere, external to buildings, to which the general public has access." The standards define levels of air quality that are necessary, with adequate margin of safety, to protect the public health (primary standards) and the public welfare (secondary standards). Standards exist for sulfur oxides (measured as sulfur dioxide), nitrogen dioxide, carbon monoxide, total suspended particulates (TSP), lead, and ozone. The standards specify the maximum pollutant concentrations and frequencies of occurrence that are allowed for specific averaging periods (e.g., the concentration of carbon monoxide when averaged over 1 hour is allowed to exceed 40 mg/m^3 only once per year). The averaging periods vary from 1 hour to 1 year, depending on the pollutant.

In 1987, the EPA proposed a revision to the particulate standard to include only particles with an aerodynamic diameter less than or equal to a nominal 10 micrometers (μm) (PM-10) (1 μm $\cong$ 0.004 in.). These standards became effective July 31, 1987, replacing the TSP standards.

State and local governments have the authority to impose standards for ambient air quality that are stricter than the national standards. Washington State has established more stringent standards for sulfur dioxide and total suspended particulates. In addition, Washington State has established

TABLE 4.1-6. Annual Average Atmospheric Diffusion Factors (χ/Q') for the Skagit-Hanford Site for Ground-Level Releases Based on 1983-1987 Data

	χ/Q' (s/m^3)									
	0.8 km	2.4 km	4.0 km	5.6 km	7.2 km	12 km	24 km	40 km	56 km	72 km
N	5.62×10^{-6}	8.82×10^{-7}	4.03×10^{-7}	2.44×10^{-7}	1.70×10^{-7}	8.19×10^{-8}	3.13×10^{-8}	1.56×10^{-8}	9.94×10^{-9}	7.11×10^{-9}
NNE	5.39×10^{-6}	8.48×10^{-7}	3.88×10^{-7}	2.36×10^{-7}	1.64×10^{-7}	7.95×10^{-8}	3.05×10^{-8}	1.53×10^{-8}	9.74×10^{-9}	6.98×10^{-9}
NE	5.39×10^{-6}	8.49×10^{-7}	3.89×10^{-7}	2.37×10^{-7}	1.64×10^{-7}	7.96×10^{-8}	3.05×10^{-8}	1.53×10^{-8}	9.74×10^{-9}	6.98×10^{-9}
ENE	6.00×10^{-6}	9.46×10^{-7}	4.34×10^{-7}	2.64×10^{-7}	1.84×10^{-7}	8.89×10^{-8}	3.41×10^{-8}	1.71×10^{-8}	1.09×10^{-8}	7.83×10^{-9}
E	7.12×10^{-6}	1.13×10^{-6}	5.19×10^{-7}	3.16×10^{-7}	2.20×10^{-7}	1.07×10^{-7}	4.12×10^{-8}	2.07×10^{-8}	1.32×10^{-8}	9.50×10^{-9}
ESE	1.08×10^{-5}	1.72×10^{-6}	7.90×10^{-7}	4.81×10^{-7}	3.35×10^{-7}	1.63×10^{-7}	6.27×10^{-8}	3.15×10^{-8}	2.01×10^{-8}	1.44×10^{-8}
SE	1.38×10^{-5}	2.19×10^{-6}	1.00×10^{-6}	6.10×10^{-7}	4.24×10^{-7}	2.05×10^{-7}	7.84×10^{-8}	3.92×10^{-8}	2.49×10^{-8}	1.78×10^{-8}
SSE	7.92×10^{-6}	1.25×10^{-6}	5.68×10^{-7}	3.44×10^{-7}	2.39×10^{-7}	1.15×10^{-7}	4.36×10^{-8}	2.17×10^{-8}	1.38×10^{-8}	9.83×10^{-9}
S	7.15×10^{-6}	1.11×10^{-6}	5.02×10^{-7}	3.03×10^{-7}	2.09×10^{-7}	9.94×10^{-8}	3.73×10^{-8}	1.84×10^{-8}	1.16×10^{-8}	8.24×10^{-9}
SSW	2.69×10^{-6}	4.14×10^{-7}	1.86×10^{-7}	1.12×10^{-7}	7.72×10^{-8}	3.67×10^{-8}	1.37×10^{-8}	6.73×10^{-9}	4.24×10^{-9}	3.01×10^{-9}
SW	2.54×10^{-6}	3.92×10^{-7}	1.76×10^{-7}	1.06×10^{-7}	7.28×10^{-8}	3.45×10^{-8}	1.28×10^{-8}	6.30×10^{-9}	3.96×10^{-9}	2.81×10^{-9}
WSW	2.44×10^{-6}	3.75×10^{-7}	1.69×10^{-7}	1.01×10^{-7}	6.98×10^{-8}	3.31×10^{-8}	1.23×10^{-8}	6.06×10^{-9}	3.82×10^{-9}	2.71×10^{-9}
W	2.87×10^{-6}	4.38×10^{-7}	1.97×10^{-7}	1.18×10^{-7}	8.13×10^{-8}	3.86×10^{-8}	1.44×10^{-8}	7.08×10^{-9}	4.47×10^{-9}	3.18×10^{-9}
WNW	4.23×10^{-6}	6.50×10^{-7}	2.94×10^{-7}	1.77×10^{-7}	1.22×10^{-7}	5.85×10^{-8}	2.20×10^{-8}	1.09×10^{-8}	6.91×10^{-9}	4.93×10^{-9}
NW	5.78×10^{-6}	9.00×10^{-7}	4.09×10^{-7}	2.47×10^{-7}	1.71×10^{-7}	8.17×10^{-8}	3.08×10^{-8}	1.53×10^{-8}	9.67×10^{-9}	6.90×10^{-9}
NNW	5.87×10^{-6}	9.20×10^{-7}	4.19×10^{-7}	2.54×10^{-7}	1.76×10^{-7}	8.49×10^{-8}	3.23×10^{-8}	1.61×10^{-8}	1.03×10^{-8}	7.33×10^{-9}

TABLE 4.1-7. Annual Average Atmospheric Diffusion Factors (χ/Q') for the 200-East Area for an 89-m Release Based on 1983-1987 Data

	χ/Q' (s/m^3)									
	0.8 km	2.4 km	4.0 km	5.6 km	7.2 km	12 km	24 km	40 km	56 km	72 km
N	6.28×10^{-8}	3.81×10^{-8}	3.21×10^{-8}	2.64×10^{-8}	2.20×10^{-8}	1.43×10^{-8}	7.37×10^{-9}	4.36×10^{-9}	3.06×10^{-9}	2.33×10^{-9}
NNE	2.83×10^{-8}	2.25×10^{-8}	1.90×10^{-8}	1.54×10^{-8}	1.27×10^{-8}	7.99×10^{-9}	3.96×10^{-9}	2.29×10^{-9}	1.59×10^{-9}	1.20×10^{-9}
NE	3.43×10^{-8}	2.54×10^{-8}	2.22×10^{-8}	1.82×10^{-8}	1.50×10^{-8}	9.55×10^{-9}	4.73×10^{-9}	2.73×10^{-9}	1.88×10^{-9}	1.42×10^{-9}
ENE	5.02×10^{-8}	3.14×10^{-8}	2.74×10^{-8}	2.27×10^{-8}	1.90×10^{-8}	1.23×10^{-8}	6.27×10^{-9}	3.68×10^{-9}	2.56×10^{-9}	1.95×10^{-9}
E	6.62×10^{-8}	6.81×10^{-8}	6.46×10^{-8}	5.53×10^{-8}	4.71×10^{-8}	3.14×10^{-8}	1.65×10^{-8}	9.83×10^{-9}	6.91×10^{-9}	5.28×10^{-9}
ESE	7.70×10^{-8}	9.62×10^{-8}	8.70×10^{-8}	7.21×10^{-8}	6.01×10^{-8}	3.87×10^{-8}	1.94×10^{-8}	1.13×10^{-8}	7.79×10^{-9}	5.89×10^{-9}
SE	1.06×10^{-7}	8.66×10^{-8}	7.05×10^{-8}	5.57×10^{-8}	4.52×10^{-8}	2.77×10^{-8}	1.32×10^{-8}	7.49×10^{-9}	5.10×10^{-9}	3.82×10^{-9}
SSE	9.92×10^{-8}	6.13×10^{-8}	4.80×10^{-8}	3.72×10^{-8}	2.96×10^{-8}	1.76×10^{-8}	8.16×10^{-9}	4.52×10^{-9}	3.05×10^{-9}	2.27×10^{-9}
S	1.59×10^{-7}	8.24×10^{-8}	6.09×10^{-8}	4.58×10^{-8}	3.58×10^{-8}	2.05×10^{-8}	9.08×10^{-9}	4.89×10^{-9}	3.25×10^{-9}	2.39×10^{-9}
SSW	1.05×10^{-7}	5.38×10^{-8}	3.91×10^{-8}	2.91×10^{-8}	2.26×10^{-8}	1.28×10^{-8}	5.57×10^{-9}	2.95×10^{-9}	1.94×10^{-9}	1.41×10^{-9}
SW	8.68×10^{-8}	5.30×10^{-8}	3.99×10^{-8}	3.00×10^{-8}	2.34×10^{-8}	1.33×10^{-8}	5.84×10^{-9}	3.13×10^{-9}	2.07×10^{-9}	1.52×10^{-9}
WSW	9.78×10^{-8}	5.21×10^{-8}	3.77×10^{-8}	2.79×10^{-8}	2.16×10^{-8}	1.22×10^{-8}	5.29×10^{-9}	2.83×10^{-9}	1.87×10^{-9}	1.37×10^{-9}
W	1.52×10^{-7}	7.83×10^{-8}	5.84×10^{-8}	4.42×10^{-8}	3.48×10^{-8}	2.02×10^{-8}	9.09×10^{-9}	4.96×10^{-9}	3.32×10^{-9}	2.46×10^{-9}
WNW	1.02×10^{-7}	5.49×10^{-8}	4.21×10^{-8}	3.25×10^{-8}	2.59×10^{-8}	1.55×10^{-8}	7.25×10^{-9}	4.06×10^{-9}	2.76×10^{-9}	2.07×10^{-9}
NW	8.34×10^{-8}	5.34×10^{-8}	4.23×10^{-8}	3.32×10^{-8}	2.68×10^{-8}	1.64×10^{-8}	7.89×10^{-9}	4.50×10^{-9}	3.09×10^{-9}	2.33×10^{-9}
NNW	5.23×10^{-8}	3.87×10^{-8}	3.22×10^{-8}	2.59×10^{-8}	2.13×10^{-8}	1.34×10^{-8}	6.72×10^{-9}	3.93×10^{-9}	2.74×10^{-9}	2.08×10^{-9}

TABLE 4.1-8. Annual Average Atmospheric Diffusion Factors (χ/Q') for the 200-East Area for a Ground-Level Release Based on 1983-1987 Data

	χ/Q' (s/m^3)									
	0.8 km	2.4 km	4.0 km	5.6 km	7.2 km	12 km	24 km	40 km	56 km	72 km
N	3.87×10^{-6}	6.08×10^{-7}	2.79×10^{-7}	1.70×10^{-7}	1.18×10^{-7}	5.72×10^{-8}	2.20×10^{-8}	1.10×10^{-8}	7.05×10^{-9}	5.06×10^{-9}
NNE	2.04×10^{-6}	3.21×10^{-7}	1.47×10^{-7}	8.93×10^{-8}	6.20×10^{-8}	3.00×10^{-8}	1.15×10^{-8}	5.75×10^{-9}	3.67×10^{-9}	2.63×10^{-9}
NE	2.43×10^{-6}	3.83×10^{-7}	1.75×10^{-7}	1.06×10^{-7}	7.39×10^{-8}	3.57×10^{-8}	1.37×10^{-8}	6.84×10^{-9}	4.35×10^{-9}	3.12×10^{-9}
ENE	3.30×10^{-6}	5.18×10^{-7}	2.37×10^{-7}	1.44×10^{-7}	1.00×10^{-7}	4.86×10^{-8}	1.86×10^{-8}	9.33×10^{-9}	5.95×10^{-9}	4.27×10^{-9}
E	8.99×10^{-6}	1.42×10^{-6}	6.54×10^{-7}	3.99×10^{-7}	2.77×10^{-7}	1.35×10^{-7}	5.19×10^{-8}	2.60×10^{-8}	1.66×10^{-8}	1.19×10^{-8}
ESE	9.59×10^{-6}	1.52×10^{-6}	6.94×10^{-7}	4.22×10^{-7}	2.93×10^{-7}	1.41×10^{-7}	5.40×10^{-8}	2.69×10^{-8}	1.71×10^{-8}	1.23×10^{-8}
SE	6.34×10^{-6}	9.93×10^{-7}	4.52×10^{-7}	2.73×10^{-7}	1.89×10^{-7}	9.08×10^{-8}	3.44×10^{-8}	1.71×10^{-8}	1.08×10^{-8}	7.74×10^{-9}
SSE	3.91×10^{-6}	6.07×10^{-7}	2.75×10^{-7}	1.66×10^{-7}	1.15×10^{-7}	5.50×10^{-8}	2.08×10^{-8}	1.03×10^{-8}	6.51×10^{-9}	4.64×10^{-9}
S	4.24×10^{-6}	6.51×10^{-7}	2.93×10^{-7}	1.76×10^{-7}	1.21×10^{-7}	5.75×10^{-8}	2.14×10^{-8}	1.05×10^{-8}	6.63×10^{-9}	4.71×10^{-9}
SSW	2.53×10^{-6}	3.87×10^{-7}	1.73×10^{-7}	1.04×10^{-7}	7.12×10^{-8}	3.36×10^{-8}	1.24×10^{-8}	6.06×10^{-9}	3.80×10^{-9}	2.69×10^{-9}
SW	2.98×10^{-6}	4.61×10^{-7}	2.08×10^{-7}	1.25×10^{-7}	8.57×10^{-8}	4.06×10^{-8}	1.51×10^{-8}	7.37×10^{-9}	4.63×10^{-9}	3.28×10^{-9}
WSW	2.60×10^{-6}	3.99×10^{-7}	1.79×10^{-7}	1.07×10^{-7}	7.39×10^{-8}	3.50×10^{-8}	1.30×10^{-8}	6.37×10^{-9}	4.01×10^{-9}	2.84×10^{-9}
W	4.45×10^{-6}	6.86×10^{-7}	3.10×10^{-7}	1.87×10^{-7}	1.29×10^{-7}	6.15×10^{-8}	2.31×10^{-8}	1.14×10^{-8}	7.22×10^{-9}	5.14×10^{-9}
WNW	3.65×10^{-6}	5.66×10^{-7}	2.57×10^{-7}	1.55×10^{-7}	1.07×10^{-7}	5.15×10^{-8}	1.95×10^{-8}	9.67×10^{-9}	6.14×10^{-9}	4.38×10^{-9}
NW	3.67×10^{-6}	5.72×10^{-7}	2.61×10^{-7}	1.58×10^{-7}	1.09×10^{-7}	5.26×10^{-8}	2.00×10^{-8}	9.97×10^{-9}	6.34×10^{-9}	4.53×10^{-9}
NNW	3.56×10^{-6}	5.60×10^{-7}	2.56×10^{-7}	1.56×10^{-7}	1.08×10^{-7}	5.24×10^{-8}	2.01×10^{-8}	1.00×10^{-8}	6.40×10^{-9}	4.59×10^{-9}

9 3 1 2 8 5 4 0 0 3 0

TABLE 4.1-9. Annual Average Atmospheric Diffusion Factors (χ/Q') for the 400 Area for a Ground-Level Release Based on 1983-1987 Data

	χ/Q' (s/m^3)									
	0.8 km	2.4 km	4.0 km	5.6 km	7.2 km	12 km	24 km	40 km	56 km	72 km
N	7.73×10^{-6}	1.21×10^{-6}	5.55×10^{-7}	3.37×10^{-7}	2.34×10^{-7}	1.13×10^{-7}	4.31×10^{-8}	2.15×10^{-8}	1.37×10^{-8}	9.81×10^{-9}
NNE	5.18×10^{-6}	8.12×10^{-7}	3.70×10^{-7}	2.24×10^{-7}	1.55×10^{-7}	7.47×10^{-8}	2.84×10^{-8}	1.41×10^{-8}	8.96×10^{-9}	6.40×10^{-9}
NE	3.35×10^{-6}	5.25×10^{-7}	2.40×10^{-7}	1.45×10^{-7}	1.01×10^{-7}	4.85×10^{-8}	1.84×10^{-8}	9.18×10^{-9}	5.83×10^{-9}	4.17×10^{-9}
ENE	2.17×10^{-6}	3.40×10^{-7}	1.55×10^{-7}	9.40×10^{-8}	6.51×10^{-8}	3.13×10^{-8}	1.19×10^{-8}	5.90×10^{-9}	3.74×10^{-9}	2.67×10^{-9}
E	3.63×10^{-6}	5.71×10^{-7}	2.60×10^{-7}	1.58×10^{-7}	1.09×10^{-7}	5.24×10^{-8}	1.99×10^{-8}	9.87×10^{-9}	6.26×10^{-9}	4.47×10^{-9}
ESE	4.00×10^{-6}	6.30×10^{-7}	2.87×10^{-7}	1.73×10^{-7}	1.20×10^{-7}	5.74×10^{-8}	2.17×10^{-8}	1.07×10^{-8}	6.77×10^{-9}	4.82×10^{-9}
SE	5.22×10^{-6}	8.24×10^{-7}	3.75×10^{-7}	2.27×10^{-7}	1.57×10^{-7}	7.55×10^{-8}	2.86×10^{-8}	1.42×10^{-8}	8.98×10^{-9}	6.40×10^{-9}
SSE	4.22×10^{-6}	6.65×10^{-7}	3.03×10^{-7}	1.84×10^{-7}	1.27×10^{-7}	6.12×10^{-8}	2.32×10^{-8}	1.15×10^{-8}	7.32×10^{-9}	5.23×10^{-9}
S	5.50×10^{-6}	8.62×10^{-7}	3.93×10^{-7}	2.39×10^{-7}	1.65×10^{-7}	7.97×10^{-8}	3.04×10^{-8}	1.52×10^{-8}	9.65×10^{-9}	6.90×10^{-9}
SSW	3.23×10^{-6}	5.04×10^{-7}	2.30×10^{-7}	1.39×10^{-7}	9.67×10^{-8}	4.66×10^{-8}	1.78×10^{-8}	8.89×10^{-9}	5.66×10^{-9}	4.05×10^{-9}
SW	2.31×10^{-6}	3.61×10^{-7}	1.64×10^{-7}	9.91×10^{-8}	6.86×10^{-8}	3.29×10^{-8}	1.25×10^{-8}	6.19×10^{-9}	3.93×10^{-9}	2.80×10^{-9}
WSW	1.71×10^{-6}	2.65×10^{-7}	1.20×10^{-7}	7.28×10^{-8}	5.03×10^{-8}	2.41×10^{-8}	9.12×10^{-9}	4.53×10^{-9}	2.87×10^{-9}	2.05×10^{-9}
W	2.43×10^{-6}	3.76×10^{-7}	1.71×10^{-7}	1.03×10^{-7}	7.14×10^{-8}	3.43×10^{-8}	1.30×10^{-8}	6.47×10^{-9}	4.11×10^{-9}	2.94×10^{-9}
WNW	2.24×10^{-6}	3.47×10^{-7}	1.57×10^{-7}	9.47×10^{-8}	6.54×10^{-8}	3.13×10^{-8}	1.18×10^{-8}	5.83×10^{-9}	3.69×10^{-9}	2.63×10^{-9}
NW	2.94×10^{-6}	4.57×10^{-7}	2.08×10^{-7}	1.26×10^{-7}	8.69×10^{-8}	4.17×10^{-8}	1.58×10^{-8}	7.84×10^{-9}	4.97×10^{-9}	3.55×10^{-9}
NNW	4.52×10^{-6}	7.10×10^{-7}	3.24×10^{-7}	1.97×10^{-7}	1.36×10^{-7}	6.57×10^{-8}	2.50×10^{-8}	1.25×10^{-8}	7.94×10^{-9}	5.68×10^{-9}

standards for volatile organic compounds (VOC), arsenic, fluoride, and other pollutants that are not covered by national standards. The state standards for carbon monoxide and nitrogen dioxide are identical to the national standards. At the local level, the Tri-County (Benton, Franklin, and Walla Walla) Air Pollution Control Authority has the authority to establish more stringent air standards, but has established no more recent local standards. Table 4.1-10 summarizes the pertinent NAAQS (federal and supplemental state standards) and the maximum background concentrations that have been measured in the vicinity of the Hanford Site.

Major Stationary Emission Sources. Emission inventories for permitted pollution sources in Benton, Franklin, and Walla Walla Counties are routinely compiled by the Tri-County Air Pollution Control Board. Table 4.1-11 lists the annual emission rates for stationary sources within the Hanford Site boundaries that have been reported to the Washington State Department of Ecology (Ecology) by the Department of Energy (DOE).

Onsite Monitoring. The most recent monitoring data available are from 1988. The only onsite monitoring conducted during this year was for nitrogen dioxide (Jaquish and Bryce 1989); NO_2 was monitored at seven locations within the Hanford Site.[a] The highest annual average concentration was 9 $\mu g/m^3$ (0.005 ppm), well below the applicable federal and Washington State annual ambient standard of 100 $\mu g/m^3$ (5 ppm).

Monitoring of TSP was discontinued for 1988 when the Basalt Waste Isolation Project, for which those measurements were required, was concluded.

Offsite Monitoring. The only offsite monitoring in the vicinity of the Hanford Site in 1989 was that conducted by Ecology for PM-10. PM-10 was monitored at two locations, at Columbia Center in Kennewick and at Wallula. During 1989, the 24-hour PM-10 standard of 150 $\mu g/m^3$ was exceeded on two occasions at the Columbia Center monitoring location; it was not exceeded at Wallula. These PM-10 monitoring results are summarized in Table 4.1-12.

(a) Nitrogen dioxide sampling and analysis were performed by the Hanford Environmental Health Foundation (HEHF).

TABLE 4.1-10. Ambient Air Quality Standards (AAQS) and Maximum Measured Concentrations of Significant Pollutants at the Hanford Site ($\mu g/m^3$)

Pollutant	National Primary Standard	National Secondary Standard	Supp. State Standard	Maximum Background Concentration
Nitrogen Dioxide (NO_2)				
Annual arithmetic mean	100	100	--	36
Sulfur Dioxide (SO_2)				
Annual arithmetic mean	80	80	52	0.5
24-h maximum[a]	365	365	260	6
3-h maximum[a]	--	1,300	--	20
1-h maximum[a]	--	--	1,018	49
1-h maximum[b]	--	--	655	49
Carbon Monoxide (CO)				
8-h maximum[a]	10,000	10,000	--	6,500
1-h maximum[a]	40,000	40,000	--	11,800
Total Suspended Particulates[c]				
Annual geometric mean	75	60	40[d]	56
24-h maximum[a]	260	150	120[d]	356

(a) Not to be exceeded more than once per year.
(b) Not to be exceeded more than two times in any consecutive 7 days.
(c) If the annual background concentration in eastern Washington State exceeds 20 $\mu g/m^3$ or the 24-h background concentrations exceeds 30 $\mu g/m^3$ due to high levels of rural fugitive dust, the primary and secondary AAQS are replaced by a State standard that specifies the maximum allowable pollutant concentration independent of the background concentration of that pollutant.
(d) Plus background.

Background Concentrations. During the past 10 years, carbon monoxide, sulfur dioxide, and nitrogen dioxide have been monitored periodically in communities and commercial areas southeast of Hanford. These urban measurements are typically used to estimate the maximum background pollutant concentrations for the Hanford Site because of the lack of specific onsite monitoring. Because these measurements were made in the vicinity of local

TABLE 4.1-11. Emission Rates (t/yr) for Stationary Emission Sources Within the Hanford Site for 1988

	Source	Criteria Pollutant Part.	SO_2	NO_x	VOC	CO
1.	100-N Boiler	16	380	120	5.1	25
2.	100-N Boiler	8	210	60	2.5	13
3.	300 Area Boiler #2	0.2	2.7	0.6	0.0	0.1
4.	300 Area Boiler #3	3.7	76	43	2.9	5.7
5.	300 Area Boiler #4	4.1	83	47	3.1	6.3
6.	300 Area Boiler #5	4.6	94	53	3.5	7.0
7.	300 Area Boiler #6	0	0	0	0	0
8.	200-East Boilers	213	293	447	30	60
9.	200-West Boilers	99	369	208	14	28
10.	1100 Area Boiler	0.2	0.8	1.2	0	.05
11.	1100 Area Boiler	0.4	1.1	1.8	0	.05
12.	200-East and 200-West Fugitive Coal Piles	100	0	0	0	0
13.	Fugitive Emissions	1	0	0	0	0
14.	Backup Boiler, 200-East Area	1	4	6	.01	.21

TABLE 4.1-12. Results of Particulate ($\mu g/m^3$) Monitoring Near the Hanford Site in 1989[a]

Location	Annual Geographic Mean	Maximum Concentration	Number of Occurrences >150
Kennewick Columbia Center	29	279	2
Wallula	37	121	0

(a) Source: "Washington State Air Monitoring Data for 1988," State Department of Ecology, Olympia, Washington sources of pollution, they will overestimate maximum background concentrations within the Hanford Site or at the site boundaries.

Particulate concentrations can reach relatively high levels in eastern Washington State because of exceptional natural events (i.e., dust storms, volcanic eruptions, and large brushfires) that occur in the region. Washington State ambient air quality standards do not consider "rural fugitive dust" from exceptional natural events when estimating the maximum background concentrations of particulates in the area east of the Cascade Mountain crest. Similarly, the EPA also exempts the rural fugitive dust component of background concentrations when considering permit applications and enforcement of air quality standards.

4.1.8 <u>100 Areas</u>

The surface wind pattern at the 100-N Area (see Figure 4.2-8 for location of 100 Areas) is greatly affected by the topographic influence of the Columbia River. The wind rose for station 13 (see Figure 4.1-2) shows a prevailing wind direction from the west-southwest (along the river) at the 10-m level. The 60-m tower at the 100-N Area provides additional data to define the wind at 60 m (200 ft), which is influenced less by surface features than the 10-m instrument. However, because this tower is relatively new (1986), data are currently being collected and will not be available until 1990.

Temperature measurements for this area were also initiated at the time that the 60-m tower was erected. Temperature difference measurements between the 60-m and 10-m levels provide information for determining atmospheric stability, a parameter important to atmospheric dispersion calculations. These data are being collected and will be available in 1990. In the interim, the χ/Q values in Table 4.1-6 may be used.

4.1.9 <u>300 Area</u>

The wind rose for the 300 Area (Station 11) shows that the largest (and approximately the same) percentages of wind blow from the northwest/north-northwest and south-southwest/southwest directions (see Figure 4.1-2); however, the winds from the southwest quadrant tend to be stronger.

Data collected by Washington Public Power Supply System for WNP-1 and data collected from the 10-m towers at the 300 and 400 Areas have been significantly different. Because these locations are relatively close together, Pacific Northwest Laboratory (PNL) constructed 60-m towers in the 300 and 400 Areas in 1986 to provide additional wind and temperature information to further define meteorological conditions in this area.

Data from these towers are being collected and will be available in 1990.

4.2 GEOLOGY AND HYDROLOGY

4.2.1 Geology and Physiography

The region of the Pacific Northwest that contains the Hanford Site lies within the Columbia Intermontane physiographic province, which is bordered on the north and east by the Rocky Mountains and on the west by the Cascade Range (Figure 4.2-1). This province has been a topographic and structural depression since the early Miocene, and is subdivided into smaller physiographic units based primarily on topography and structural geologic history. The dominant geologic characteristics of the Columbia Intermontane Province have resulted from flood basalt volcanism. Flows of the Columbia River Basalt Group were extruded from linear vents in southeastern Washington, northeastern Oregon, and west-central Idaho between about 17 and 6 million years (my) before the present time. The ancient basalt surface has subsequently been modified by tectonism, volcanism, weathering, and erosion.

The Columbia Intermontane Province is distinguished primarily by its relatively uniform rock type and undeformed nature with respect to adjacent provinces that developed under different tectonic and climatic settings. Within the Columbia Intermontane Province, the term Columbia Plateau is used informally to designate the area that is covered by the Columbia River Basalt Group.

The Columbia Intermontane Province is divided into four subprovinces. The Hanford Site is located within one of these, the Columbia Basin subprovince, which contains most of the Columbia River Basalt Group. This

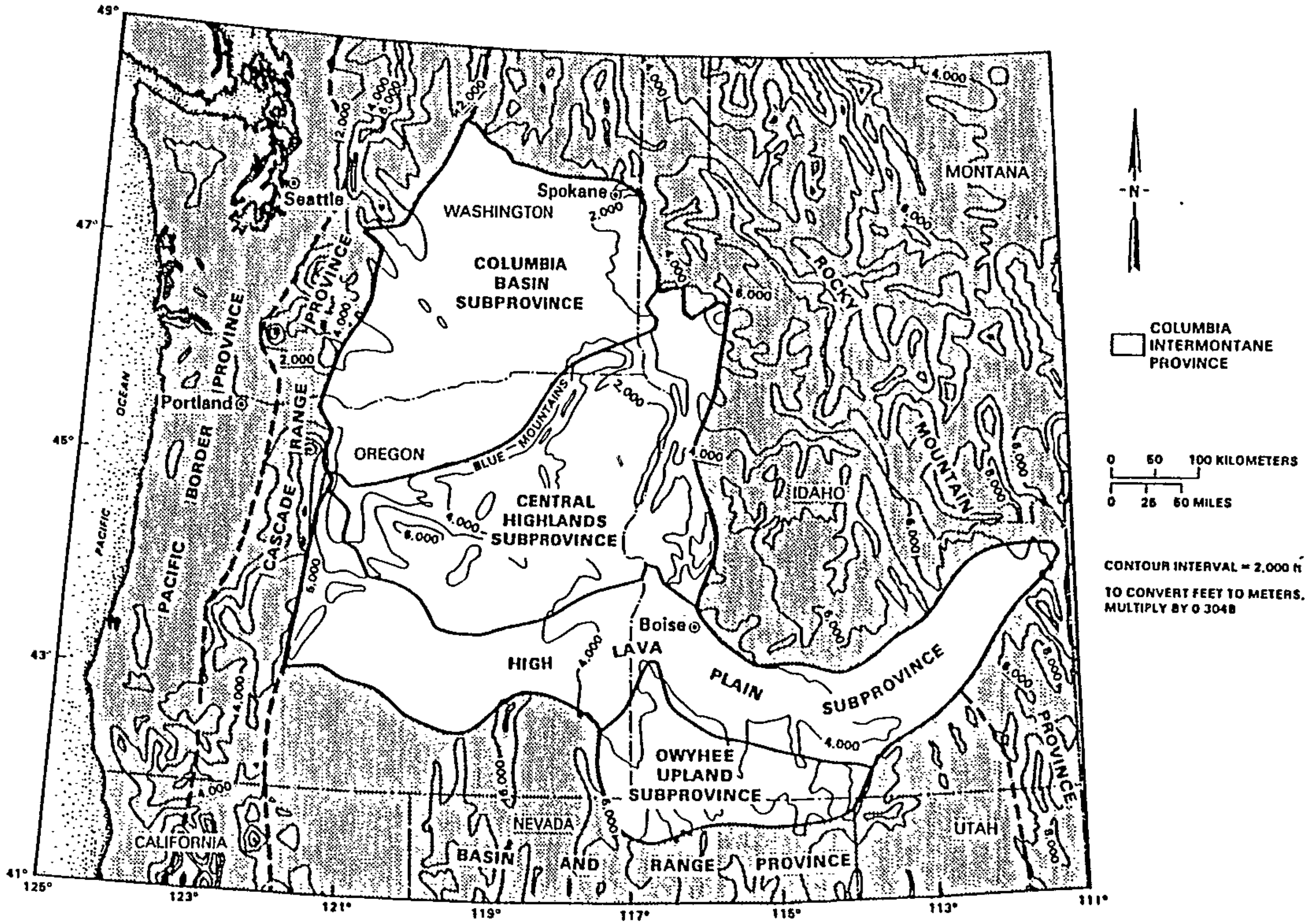


FIGURE 4.2-1. Divisions of the Columbia Intermontane Province and Adjacent Provinces (DOE 1988)

subprovince is bounded by the Cascade Range on the west, the northern Rocky Mountains on the north and east, and the Blue Mountains to the south.

Much of the Columbia Basin subprovince was affected by proglacial cataclysmic flooding associated with the sudden release of water from glacial Lake Missoula. Cataclysmic floods have been responsible for much of the present morphology of the Channeled Scabland and Central Plains section. The number and timing of the proglacial flood events are not agreed on, with estimates of the number of separate late-Pleistocene floods ranging from 2 to 40 (DOE 1988). Geological evidence suggests that glacial activity has been limited to the margins of the Columbia Basin subprovince. The maximum extent of the ice is defined by the well-developed Withrow Moraine, which lies approximately 110 km (68 mi) north of the Pasco Basin (DOE 1988).

Fluvial and lacustrine processes associated with the ancestral Columbia River system, which includes the ancestral Snake and Yakima rivers, have been active since the late Miocene. Deposits of these rivers and lakes are represented by the Ringold Formation and indicate that deposition was almost continuous from about 10.5 million years before present (mybp) until about 3.5 mybp (DOE 1988). Sometime before 900,000 years ago, a major change in regional base level resulted in fluvial incision of as much as 150 m (500 ft). The post-Ringold erosional surface was partially filled with locally derived alluvium before or between periods of Pleistocene flooding. However, in most areas of the Columbia Basin subprovince, the record of Pleistocene fluvial activity was destroyed by cataclysmic flooding. Loess occurs in sheets that mantle much of the upland areas of the Columbia Basin subprovince.

Quaternary volcanism has been limited to the extreme western margin of the Columbia Basin subprovince and is associated with the Cascade Range Province. Airfall tephra from at least three Cascade volcanoes has blanketed the central Columbia Plateau since the late Pleistocene. This tephra includes material from several eruptions of Mount St. Helens before the May 1980 eruption. Other volcanoes have erupted less frequently; two closely spaced eruptions from Glacier Peak about 11,200 years ago, and the eruption of Mount Mazama about 6,600 years ago. Generally tephra layers have not exceeded more than a few centimeters in thickness, with the exception of the Mount Mazama eruption when as much as 10 cm (3.9 in.) of tephra fell over eastern Washington (DOE 1988).

There are several major volcanoes in the Cascade Range west of the Hanford Site. The nearest volcano is Mount Adams, which is about 165 km (102 mi) from the Hanford Site, and the most active is Mount St. Helens, which is approximately 220 km (136 mi) west-southwest from Hanford.

A period of renewed volcanic activity at Mount St. Helens began in March 1980 and climaxed in a major eruption on May 18, 1980. This eruption resulted in about 1 mm (0.039 in.) of ash fall over a 9-hour period at the Hanford Site, which was near the southern edge of the ash dispersal plume. Smaller eruptions of steam and ash occurred through October 1980, but none of these deposited measurable amounts of ash at the site.

The relatively low-relief, dry Columbia Basin subprovince is further divided into six physiographic sections. The Hanford Site is located in parts of two of these: the Yakima Folds and the Central Plains sections.

The Yakima Folds section consists of east-west trending, asymmetrical anticlinal folds that plunge eastward where they merge with the low-relief Central Plains section. The east-west trending folds have formed ridges that are believed to have developed because of north-south compression and crustal shortening that has been active since the middle Miocene. The ridges have been undergoing degradation through weathering, mass wasting, and fluvial processes while the intervening synclinal valleys have aggraded intermittently with fluvial, proglacial, and eolian deposits since extrusion of the Columbia River Basalt. Average rates of uplift and subsidence on these folds are estimated at less than 40 m/my (less than 130 ft/my) (DOE 1988).

The Central Plains section includes the low-relief areas of the central Columbia Basin subprovince adjacent to and between the Yakima Folds. The Central Plains were significantly modified by erosion and deposition during the Pleistocene. The Central Plains section, as well as the rest of the Columbia Basin subprovince, has remained essentially unchanged since about 13,000 years ago except for minor fluvial and eolian activity. Loess deposits in the Pasco Basin are relatively thin [5 to 10 m (16 to 32 ft)]. Dune sand occurs in northeast-trending, longitudinally shaped dunes in the south-central and eastern parts of the Pasco Basin. The dunes reflect the predominantly southwesterly direction of strong winds across the basin. Two major structural basins, the Quincy and the Pasco, are contained within the Central Plains section.

The Hanford Site is located within the Pasco Basin in a semiarid region of southeastern Washington State. This portion of the state lies within the Columbia Plateau, which is defined generally by a thick accumulation of basaltic lava flows that extend laterally from central Washington eastward into Idaho and southward into Oregon (Tallman et al. 1979).

The Hanford Site overlies the structural low point of the Pasco Basin near the confluence of the Yakima and Columbia rivers. The boundaries of the Pasco Basin are defined by anticlinal structures of basaltic rock. These structures are the Saddle Mountains to the north; the Umtanum Ridge, Yakima Ridge, and Rattlesnake Hills to the west; and the Rattlesnake Hills and a series of doubly plunging anticlines merging with the Horse Heaven Hills to the south. The terrain within the Pasco Basin is relatively flat. Its surface features were formed by catastrophic floods and have undergone little modification since, with the exception of more recently formed sand dunes (DOE 1986).

The terrain of the central and eastern parts of the Site is relatively flat (DOE 1986). The northern and western parts of the Site have moderate to steep topographic ridges composed of basalt and sediments. The central part of the Site, including the 200-Area Plateau, has undergone minimal erosion since formation by floodwaters about 13,000 years before the present.

The elevations of the alluvial plain that covers much of the Site vary from 105 m (345 ft) above mean sea level in the southeast corner to 245 m (803 ft) in the northwest. The 200-Area Plateau, in the central part of the Site, varies in elevation from 190 to 245 m (623 to 803 ft). The highest point is on Rattlesnake Mountain (1093 m or 3585 ft) at the southwestern border of the Site.

The major geologic units of the Hanford Site are, in ascending order: subbasalt rocks (inferred to be sedimentary and volcanoclastic rocks), the Columbia River Basalt Group with intercalated sediments of the Ellensburg Formation, the Ringold Formation, the Plio-Pleistocene unit, and the Hanford formation. Locally, Holocene sand, silt, and loess exist as surficial material.

Knowledge of the subasalt rocks is limited to studies of exposures along the margin of the Columbia Plateau and to a few deep boreholes drilled in the interior of the plateau (DOE 1988). No subbasalt rocks are exposed within the central interior of the Columbia Plateau, including the Pasco Basin. Interpretation of data from wells drilled in the 1980s by Shell Oil Company in the northwestern Columbia Plateau indicates that, in the central part of the Columbia Plateau, the Columbia River Basalt Group is underlain predominantly by Tertiary continental sediments (Campbell 1989).

The regional and Hanford Site geology is dominated by the thick sequence of Miocene tholeiitic continental flood basalts designated the Columbia River Basalt Group. This layered sequence consists of more than 170,600 km^3 (40,800 mi^3) of basalt covering more than 163,000 km^2 (63,000 mi^2).

The Columbia River Basalt Group is formally divided into five formations (Ledgerwood et al. 1978; Swanson et al. 1979). They are, from the oldest to the youngest: Imnaha Basalt, Picture Gorge Basalt, Grand Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt. The Imnaha and Picture Gorge basalts are not known to occur within the Pasco Basin. The upper three formations, the Grande Ronde, the Wanapum, and the Saddle Mountain basalts, collectively constitute the Yakima Basalt Subgroup (Swanson et al. 1979). The Grande Ronde Basalt is the most extensive and voluminous formation within the Columbia River Basalt Group, and represents about 87.5% by volume of this group. Detailed descriptions of the individual formations can be found in DOE (1988).

Flows of the Columbia River Basalt Group are interbedded with and overlain by Miocene-Pliocene epiclastic and volcaniclastic sediments of the Ellensburg Formation (Myers et al. 1979). The age of the Ellensburg Formation is principally Miocene, but locally may be early Pliocene. Within the Pasco

Basin, deposits of the Ellensburg Formation are restricted primarily to the Wanapum and Saddle Mountain Basalts, and the lateral extent and thickness generally increase upward in the section (DOE 1988). Interbeds or members of the Ellensburg Formation are defined based on upper- and lower-bounding basalt flows. Correlative interbeds over the central Columbia Plateau and Pasco Basin include the Vantage, Mabton, Cold Creek, Selah, and Rattlesnake Ridge units.

Late Neogene (late Miocene to Pliocene) deposits younger than the Columbia River Basalt Group are represented by the Ringold Formation in the Pasco and Quincy basins. The fluvial-lacustrine Ringold Formation was deposited in generally east-west-trending valleys by the ancestral Columbia River and its tributaries in response to the development of the Yakima Fold Belt. The Ringold Formation is classified into three facies associations or stratigraphic section types: deposits of the migrating, throughgoing ancestral Columbia and/or Snake river systems; overbank materials beyond the influence of the main river channel(s); and fanglomerate deposits found around the margins of the basin (DOE 1988).

An eolian silt and fine sand (the Plio-Pleistocene unit) overlies the Ringold Formation in the western part of the Hanford Site (Brown 1960). This silty fine sand to sandy silt was deposited when the wind reworked and redeposited Ringold sediments. Relatively high caliche contents are found in much of this unit.

The Hanford formation lies on the eroded surface of the Plio-Pleistocene unit, the Ringold Formation, or locally on the basalt bedrock. The Hanford formation consists of catastrophic flood sediments that were deposited when ice dams in western Montana and northern Idaho were breached and massive volumes of water spilled abruptly across eastern and central Washington. The floods scoured the land surface, locally eroding the Ringold Formation, the basalts, and sedimentary interbeds, leaving a network of buried channels crossing the Pasco Basin (Tallman et al. 1979). Thick sequences of sediments were deposited by several episodes of Pleistocene flooding with the last major flood sequence dated at about 13,000 years before present (Myers et al. 1979).

These sediments have locally been divided into two main facies, termed the "Pasco Gravels" facies and the "Touchet Beds" facies (Myers et al. 1979).

Volcanic deposits in the Pasco Basin are limited to occasional, thin layers of air-fall tephra from a few millimeters to 10 cm (4 in.) thick. Eolian sediments consisting of loess and sand dunes (both active and inactive) locally veneer the surface of the Hanford Site.

The Columbia Plateau is tectonically a part of the North American continental plate, and is separated from the Pacific and Juan de Fuca oceanic plates to the west by the Cascade Range, Puget-Willamette Lowland, and Coast Range geologic provinces. It is bounded on the north by the Okanogan Highlands, on the east by the Northern Rocky Mountains and Idaho Batholith, and on the south by the High Lava Plains and Snake River Plain (Figure 4.2-2). The tectonic history of the Columbia Plateau has included the eruption of the continental flood basalts of the Columbia River Basalt Group during the period of about 17 to 6 mybp, as well as volcanic activity in the Cascade Range to the west (DOE 1988).

Structurally, the Columbia Plateau is divided into three informal subprovinces: the Palouse, Blue Mountains, and Yakima Fold Belt (Figure 4.2-3). It should be noted that these are not physiographic subprovinces, even though some of the names may be the same. All but the easternmost part of the Pasco Basin is within the Yakima Fold Belt structural subprovince (DOE 1988). The Yakima Fold Belt contains four major structural elements: the Yakima Folds, Cle Elum-Wallula disturbed zone, Hog Ranch-Naneum anticline, and northwest-trending wrench faults.

The Yakima Folds are a series of continuous, narrow, asymmetric anticlines that have wavelengths between about 5 and 30 km (3 to 19 mi) and amplitudes commonly less than 1 km (less than 0.6 mi). The anticlinal ridges are separated by broad synclines or basins. The Yakima Folds are believed to have developed under generally north-south compression, but the origin and timing of the deformation along the fold structures are not well known (DOE 1988). Thrust or high-angle reverse faults are often found along both limbs of the anticlines, with the strike of the fault planes parallel or subparallel to the axis of the anticlines. There is very little direct field

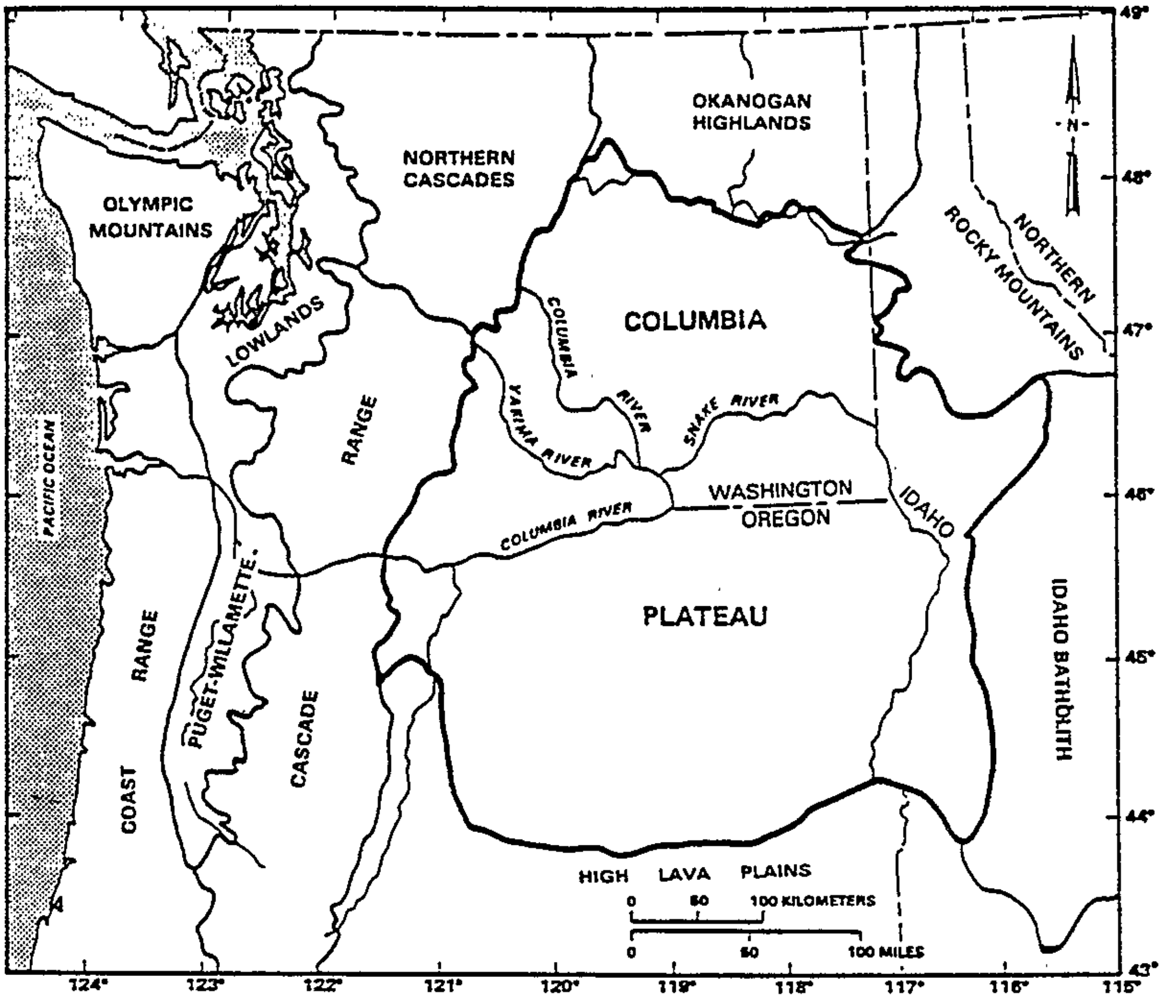


FIGURE 4.2-2. Index Map of Geologic Provinces (DOE 1988)

evidence to indicate Quaternary movement along these anticlinal ridges, and one of three cases of suspected Quaternary faulting is along the central Gable Mountain fault in the Pasco Basin.

The Cle Elum-Wallula disturbed zone is the central part of a larger topographic alignment called the Olympic-Wallowa lineament that extends from the northwestern edge of the Olympic Mountains to the northern edge of the Wallowa Mountains in Oregon. The Cle Elum-Wallula disturbed zone is a narrow zone about 10 km (6 mi) wide that transects the Yakima Fold Belt and has been divided informally into three structural domains: a broad zone of deflected

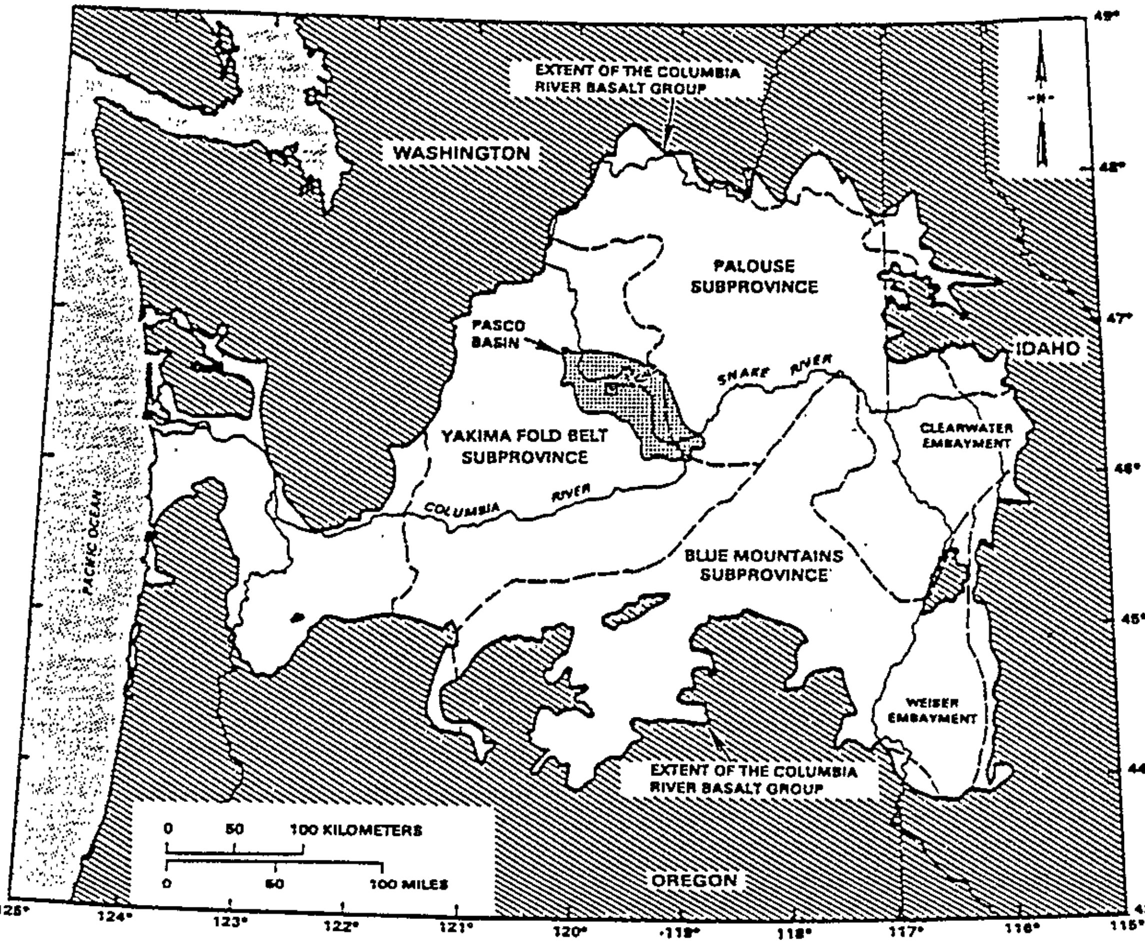


FIGURE 4.2-3. Index Map to Structural Subprovinces of the Columbia Plateau, Which Is Defined by the Distribution of Columbia River Basalt Flows East of the Cascade Range (DOE 1988)

or anomalous fold and fault trends extending south of Cle Elum, Washington, to Rattlesnake Mountain; a narrow belt of aligned domes and doubly plunging anticlines ("The Rattles") extending from Rattlesnake Mountain to Wallula Gap; and the Wallula fault zone, extending from Wallula Gap to the Blue Mountains. Evidence for Quaternary deformation has been reported for 14 localities in or directly associated with the Cle Elum-Wallula disturbed zone, but no evidence has been reported northwest of the Finley Quarry location (DOE 1988), about 60 km (36 mi) southeast of the approximate center of the Hanford Site.

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The Hog Ranch-Naneum Ridge anticline is a broad structural arch that extends from southwest of Wenatchee, Washington, to at least the Yakima Ridge. This feature defines part of the northwestern boundary of the Pasco Basin, but little is known about the structural geology of this portion of the feature, nor is the southern extent of the feature known.

Northwest-trending wrench faults have been mapped west of 120°W longitude in the Columbia Plateau (DOE 1988). The mean strike direction of the dextral wrench faults is 320°, but there are less numerous northeast-trending sinistral wrench faults that strike 013°. These structures are not known to exist in the central Columbia Plateau.

Most known faults within the Hanford area are associated with anticlinal fold axes, are thrust or reverse faults although normal faults do exist, and were probably formed concurrently with the folding (DOE 1988). Existing known faults within the Hanford area include wrench faults as long as 3 km (1.9 mi) on Gable Mountain and the Rattlesnake-Wallula alignment, which has been interpreted as a right-lateral strike-slip fault. The faults in Central Gable Mountain are considered capable by the U.S. Nuclear Regulatory Commission (NRC) criteria (10 CFR 100; see Appendix A) in that they have slightly displaced the Hanford formation gravels, but their relatively short lengths give them low seismic potential. Also, there is no observed seismicity on or near Gable Mountain. The Rattlesnake-Wallula alignment is interpreted as possibly being capable, in part because of lack of any distinct evidence to the contrary and because this structure continues along the northwest trend of faults that appear active at Wallula Gap, some 56 km (35 mi) southeast of the central part of the Hanford Site (DOE 1988).

Strike-slip faults have not been observed crosscutting the Pasco Basin. Anticlinal ridges that bound the Pasco Basin have been mapped in detail, and except for some component of dextral movement on the Rattlesnake-Wallula alignment, no strike-slip faults similar to those in the western Yakima Fold Belt have been observed (DOE 1988). Wrench faults have been observed along the ridges at boundaries between geometrically coherent segments of the structures, as in the Saddle Mountains, but these faults are confined to the individual structures and formed as different geometries developed in the fold. Similar type faults have been mapped on Gable Mountain and studied in detail. These features are also interpreted as wrench faults that are a response to folding.

In general, it has been found that for structures within the Hanford Site area the greatest deformation occurs in the hinge area of the anticlinal ridges and decreases with distance from that area; that is, the greatest amount of tectonic jointing and faulting occurs in the hinge zone and decreases toward the gently dipping limbs. The faults usually exhibit low dips with small displacements, may be confined to the layer in which they occur, and die out to no recognizable displacement in short lateral distances (DOE 1988).

4.2.2 Soils

Hajek (1966) lists and describes 15 different soil types on the Hanford Site. The soil types vary from sand to silty and sandy loam. These are shown in Figure 4.2-4 and briefly described in Table 4.2-1. Various classifications, including land use, are also given in Hajek (1966).

4.2.3 Seismicity

The historic record of earthquakes in the Pacific Northwest dates from about 1840. The early part of this record is based on newspaper reports of structural damage and human perception of the shaking, as classified by the Modified Mercalli Intensity (MMI) scale, and is probably incomplete because the region was sparsely populated. Seismograph networks did not start providing earthquake locations and magnitudes of earthquakes in the Pacific Northwest until about 1960. A comprehensive network of seismic stations that provides accurate locating information for most earthquakes larger than magnitude 2.5 was installed in eastern Washington in 1969. DOE (1988) provides a summary of the seismicity of the Pacific Northwest, a detailed review of the seismicity in the Columbia Plateau region and the Hanford Site, and a description of the seismic networks used to collect the data.

Large earthquakes (magnitude greater than Richter 7) in the Pacific Northwest have occurred in the vicinity of Puget Sound, Washington, and near the Rocky Mountains in eastern Idaho and western Montana. One of these events

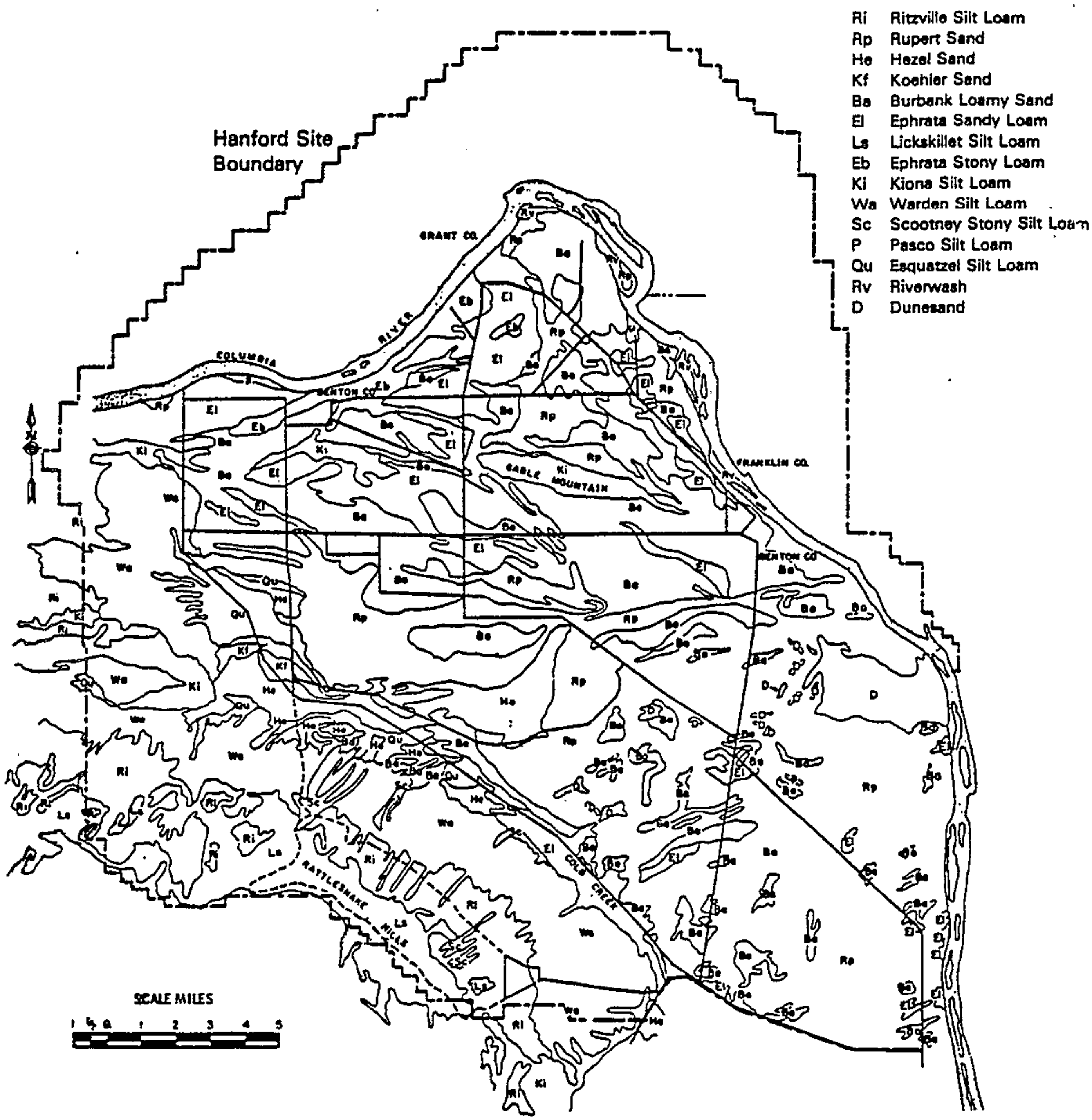

FIGURE 4.2-4. Soil Map of the Hanford Site

9 3 1 2 3 5 4 0 0 4 7

TABLE 4.2-1. Soil Types on the Hanford Site (after Hajek 1966)

Name (symbol)	Description
Ritzville Silt Loam (Ri)	Dark-colored silt loam soils midway up the slopes of the Rattlesnake Hills. Developed under bunch grass from silty wind-laid deposits mixed with small amounts of volcanic ash. Characteristically >150 cm deep, but bedrock may occur at <150 cm but >75 cm.
Rupert Sand (Rp)	One of the most extensive soils on the Hanford Site. Brown-to-grayish-brown coarse sand grading to dark grayish-brown at about 90 cm. Developed under grass, sagebrush, and hopsage in coarse sandy alluvial deposits that were mantled by wind-blown sand. Hummocky terraces and dunelike ridges.
Hazel Sand (He)	Similar to Rupert sands; however, a laminated grayish-brown strongly calcareous silt loam subsoil is usually encountered within 100 cm of the surface. Surface soil is very dark brown and was formed in wind-blown sands that mantled lake-laid sediments.
Koehler Sand (Kf)	Similar to other sandy soils on the Hanford Site. Developed in a wind-blown sand mantle. Differs from other sands in that the sand mantles a lime-silica cemented layer "Hardpan." Very dark grayish-brown surface layer is somewhat darker than Rupert. Calcareous subsoil is usually dark grayish-brown at about 45 cm.
Burbank Loamy Sand (Ba)	Dark-colored, coarse-textured soil underlain by gravel. Surface soil is usually about 40 cm thick but can be 75 cm thick. Gravel content of subsoil ranges from 20% to 80%.
Kiona Silt Loam (Ki)	Occupies steep slopes and ridges. Surface soil is very dark grayish-brown and about 10 cm thick. Dark brown subsoil contains basalt fragments 30 cm and larger in diameter. Many basalt fragments found in surface layer. Basalt rock outcrops present. A shallow stony soil normally occurring in association with Ritzville and Warden soils.
Warden Silt Loam (Wa)	Dark grayish-brown soil with a surface layer usually 23 cm thick. Silt loam subsoil becomes strongly calcareous at about 50 cm and becomes lighter colored. Granitic boulders are found in many areas. Usually >150 cm deep.

TABLE 4.2-1. (contd)

Name (symbol)	Description
Ephrata Sandy Loam (El)	Surface is dark colored and subsoil is dark grayish-brown medium-textured soil underlain by gravelly material, which may continue for many feet. Level topography.
Ephrata Stony Loam (Eb)	Similar to Ephrata sandy loam. Differs in that many large hummocky ridges are presently made up of debris released from melting glaciers. Areas between hummocks contain many boulders several feet in diameter.
Scootney Stony Silt Loam (Sc)	Developed along the north slope of Rattlesnake Hills; usually confined to floors of narrow draws or small fanshaped areas where draws open onto plains. Severely eroded with numerous basaltic boulders and fragments exposed. Surface soil is usually dark grayish-brown grading to grayish-brown in the subsoil.
Pasco Silt Loam (P)	Poorly drained very dark grayish-brown soil formed in recent alluvial material. Subsoil is variable, consisting of stratified layers. Only small areas found on Hanford Site, located in low areas adjacent to the Columbia River.
Esquatzel Silt Loam (Qu)	Deep dark-brown soil formed in recent alluvium derived from loess and lake sediments. Subsoil grades to dark grayish-brown in many areas, but color and texture of the subsoil are variable because of the stratified nature of the alluvial deposits.
Riverwash (Rv)	Wet, periodically flooded areas of sand, gravel, and boulder deposits that make up overflowed islands in the Columbia River and adjacent land.
Dune Sand (D)	Miscellaneous land type that consists of hills or ridges of sand-sized particles drifted and piled up by wind and are either actively shifted or so recently fixed or stabilized that no soil horizons have developed.
Lickskillet Silt Loam (Ls)	Occupies ridge slopes of Rattlesnake Hills and slopes >765 m elevation. Similar to Kiona series except surface soils are darker. Shallow over basalt bedrock, with numerous basalt fragments throughout the profile.

occurred near Vancouver Island in 1946, and produced a maximum MMI of VIII and a Richter magnitude of 7.3. Another large event that occurred near Olympia, Washington, in 1949 had a maximum intensity of MMI VIII and a Richter magnitude of 7.1. The two largest events near the Rocky Mountains were the 1959 Hebgen Lake earthquake in western Montana, which had a Richter magnitude of 7.5 and a MMI X, and the 1983 Borah Peak earthquake in eastern Idaho, which had a Richter magnitude of 7.3 and a MMI IX.

A large earthquake of uncertain location occurred in north-central Washington in 1872. This event had an estimated maximum MMI ranging from VIII to IX and an estimated magnitude of approximately 7. The distribution of intensities suggests a location within a broad region between Lake Chelan, Washington, and the British Columbia border.

Seismicity of the Columbia Plateau is relatively low compared to the regions of the Pacific Northwest described above. Figure 4.2-5 shows the locations of all earthquakes that occurred in the Columbia Plateau before 1969 with MMI of IV or larger and with magnitude of 3 or larger, and Figure 4.2-6 shows the locations of all earthquakes that occurred from 1969 to 1986 with magnitudes of 3 or greater. The largest known earthquake in the Columbia Plateau occurred in 1936 around Milton-Freewater, Oregon. This earthquake had a magnitude of 5.75 and a maximum MMI of VII, and was followed by a number of aftershocks that indicate a northeast-trending fault plane. Other earthquakes with magnitudes of 5 or larger and/or intensities of VI are located along the boundaries of the Columbia Plateau in a cluster near Lake Chelan extending into the northern Cascade Range; in northern Idaho and Washington; and along the boundary between the western Columbia Plateau and the Cascade Range. Three MMI VI earthquakes have occurred within the Columbia Plateau, including one event in the Milton-Freewater region in 1921, one near Yakima, Washington, in 1892, and one near Umatilla, Oregon, in 1893.

In the central portion of the Columbia Plateau, the largest earthquakes near the Hanford Site are two earthquakes that occurred in 1918 and 1973. These two events had magnitudes of 4.4 and intensity V and were located north of the Hanford Site. Earthquakes often occur in spatial and temporal clusters in the central Columbia Plateau, and are termed "earthquake swarms." The

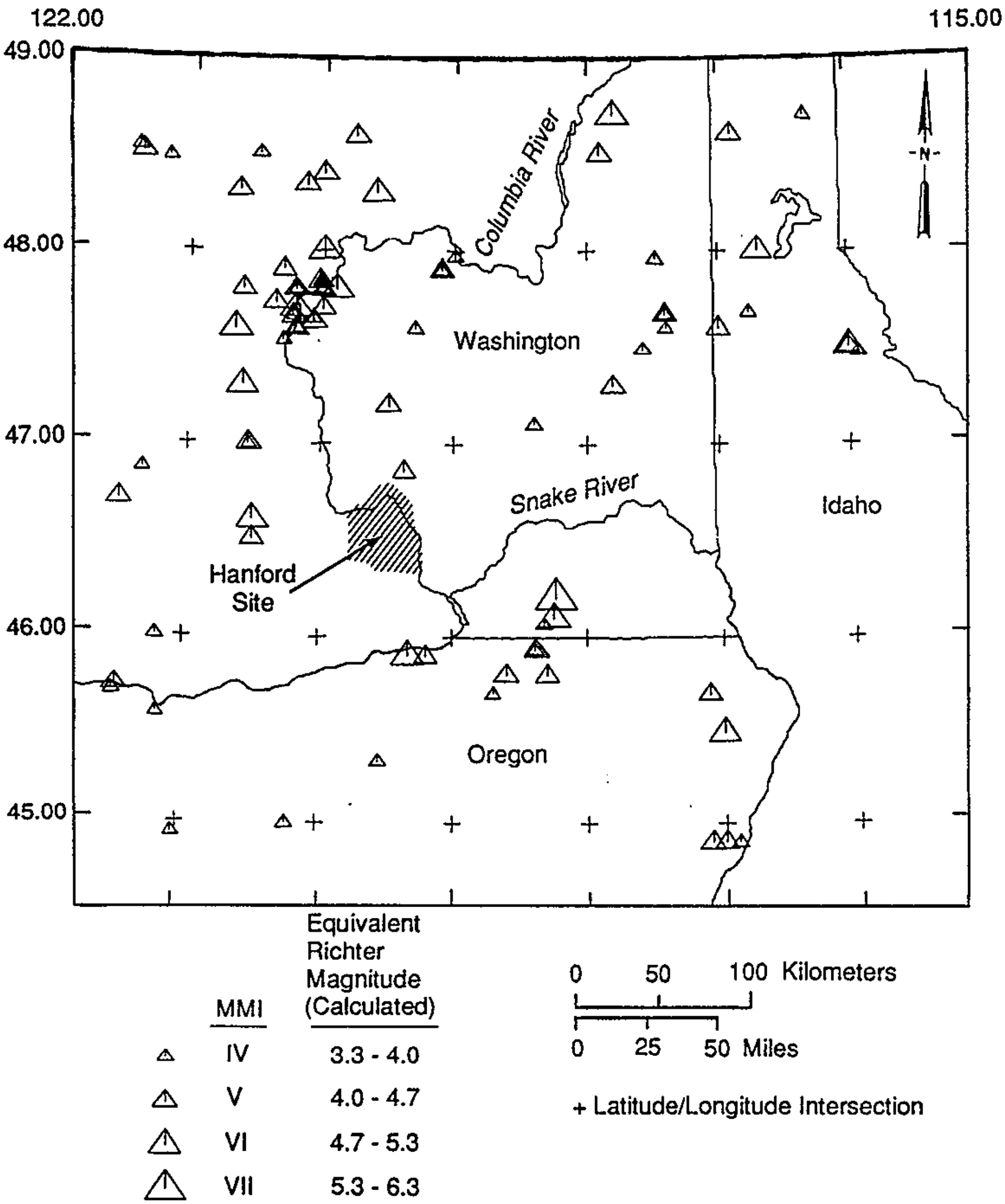

FIGURE 4.2-5. Historical Seismicity of the Columbia Plateau and Surrounding Areas. All earthquakes between 1850 and 1969 with a Modified Mercalli Intensity of IV or larger with a magnitude of 3 or greater are shown (Rohay 1989).

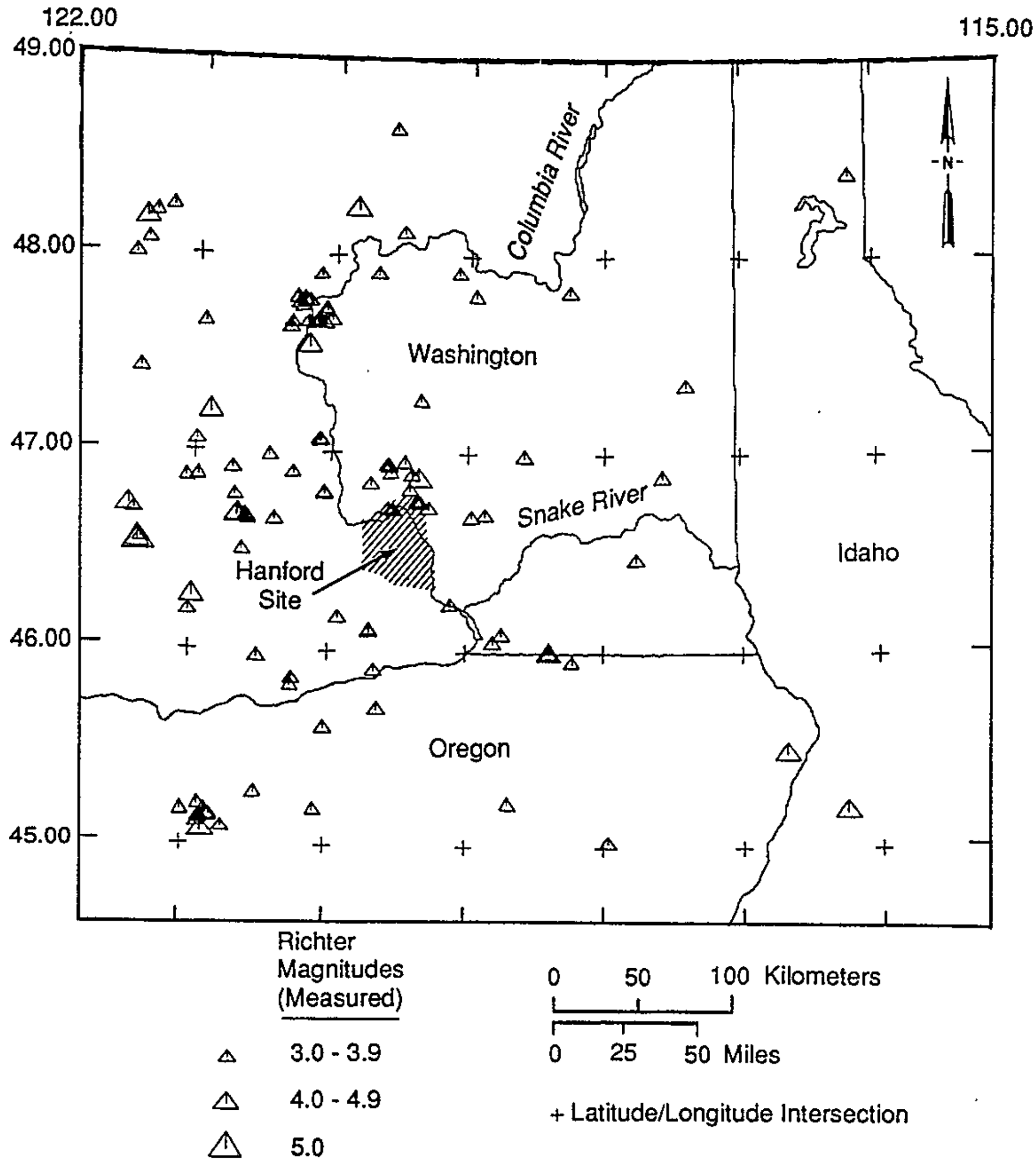

FIGURE 4.2-6. Recent Seismicity of the Columbia Plateau and Surrounding Areas as Measured by Seismographs. All earthquakes between 1969 and 1986 with a Modified Mercalli Intensity of IV or larger with a magnitude of 3 or greater are shown (Rohay 1989).

region north and east of the Hanford Site is a region of concentrated earthquake swarm activity, but earthquake swarms have also occurred in several locations within the Hanford Site.

Earthquakes in a swarm tend to gradually increase and decay in frequency of events, and there is usually no one outstanding large event within the sequence. These earthquake swarms occur at shallow depths, with 75% of the events located at depths less than 4 km (2.5 mi). Each earthquake swarm typically lasts several weeks to months, consists of several to 100 or more earthquakes, and is clustered in an area 5 to 10 km (3 to 6 mi) in lateral dimension. Often, the longest dimension of the swarm area is elongated in an east-west direction. However, detailed locations of swarm earthquakes indicate that the events occur on fault planes of variable orientation, and not on a single, throughgoing fault plane.

Earthquakes in the central Columbia Plateau also occur to depths of about 30 km (18 mi). These deeper earthquakes are less clustered and occur more often as single, isolated events. Based on seismic refraction surveys in the region, the shallow earthquake swarms are occurring in the Columbia River Basalts, and the deeper earthquakes are occurring in crustal layers below the basalts.

The spatial pattern of seismicity in the central Columbia Plateau suggests an association of the shallow swarm activity with the east-west-oriented Saddle Mountains anticline. However, this association is complex, and the earthquakes do not delineate a throughgoing fault plane that would be consistent with the faulting observed on this structure.

Earthquake focal mechanisms in the central Columbia Plateau generally indicate reverse faulting on east-west planes, consistent with a north-south-directed maximum compressive stress and with the formation of the east-west-oriented anticlinal fold of the Yakima Fold Belt (Rohay 1987). However, earthquake focal mechanisms indicate faulting on a variety of fault plane orientations.

Earthquake focal mechanisms along the western margin of the Columbia Plateau also indicate north-south compression, but here the minimum compressive stress is oriented east-west, resulting in strike-slip faulting (Rohay 1987). Geologic studies indicate an increased component of strike-slip faulting in the western portion of the Yakima Fold Belt. Earthquake focal mechanisms in the Milton-Freewater region to the southeast indicate a different stress field, one with maximum compression directed east-west instead of north-south.

Estimates for the earthquake potential of structures and zones in the central Columbia Plateau have been developed during the licensing of nuclear power plants at the Hanford Site. In reviewing the operating license application for the Washington Public Power Supply System Project WNP-2, the NRC (NRC 1982) concluded that four earthquake sources should be considered for the purpose of seismic design: the Rattlesnake-Wallula alignment, Gable Mountain, a floating earthquake in the tectonic province, and a swarm area.

For the Rattlesnake-Wallula alignment, which passes along the southwest boundary of the Hanford Site, the NRC estimated a maximum magnitude of 6.5, and for Gable Mountain, an east-west structure that passes through the northern portion of the Hanford Site, a maximum magnitude of 5.0. These estimates were based upon the inferred sense of slip, the fault length, and/or the fault area. The floating earthquake for the tectonic province was developed from the largest event located in the Columbia Plateau, the magnitude 5.75 Milton-Freewater earthquake. The maximum swarm earthquake for the purpose of WNP-2 seismic design was a magnitude 4.0 event, based on the maximum swarm earthquake in 1973. (The NRC concluded that the actual magnitude of this event was smaller than estimated previously.)

The seismic design of WNP-2 is based upon a Safe-Shutdown Earthquake (SSE) of 0.25 gravity (g; acceleration). A probabilistic seismic exposure analysis was used to determine an annual probability of 1×10^{-4} for excedance of 0.25 gravity (WPPSS 1981). For the WNP-2 site, potential earthquakes associated with the Gable Mountain structure dominated the excedance probability calculations compared to other potential sources that were considered.

4.2.4 Hydrology

Surface Water

The Pasco Basin occupies about 4900 km^2 (1900 mi^2) and is located centrally within the Columbia Basin. Elevations within the Pasco Basin are generally lower than other parts of the plateau, and surface drainage enters it from other basins. Within the Pasco Basin, the Columbia River is joined by three major tributaries: the Yakima River, the Snake River, and the Walla Walla River. No perennial streams originate within the Pasco Basin (DOE 1988).

The Hanford Site occupies approximately one-third of the land area within the Pasco Basin. Primary surface-water features associated with the Hanford Site are the Columbia and Yakima rivers. Several surface ponds and ditches are present, and are generally associated with fuel- and waste-processing activities (see Figure 4.3-6 in Ecology, Subsection 4.3).

A network of dams and multipurpose water resources projects is located along the course of the Columbia River. The principal dams are shown in Figure 4.2-7. Storage behind Grand Coulee Dam, combined with storage upstream in Canada, totals 3.1×10^{10} m^3 of usable storage to regulate the Columbia River for power, flood control, and irrigation of land within the Columbia Basin Project.

Approximately two-thirds of the Hanford Site is part of the Columbia River drainage system and about two-thirds of the surface runoff, if there were any from Hanford, would drain directly into the Columbia River along the Hanford Reach, which extends from the upstream end of Lake Wallula to the Priest Rapids Dam. The flow has been inventoried and described in detail by the U.S. Army Corps of Engineers (DOE 1986). Flow along this reach is controlled by the Priest Rapids Dam. Several drains and intakes are also present along this reach. These include irrigation outfalls from the Columbia Basin Irrigation Project and Hanford Site intakes for the onsite water export system.

Recorded flow rates of the Columbia River have ranged from 4,500 to 18,000 cubic meters per second (cms) [~158,900 to 635,600 cubic feet per

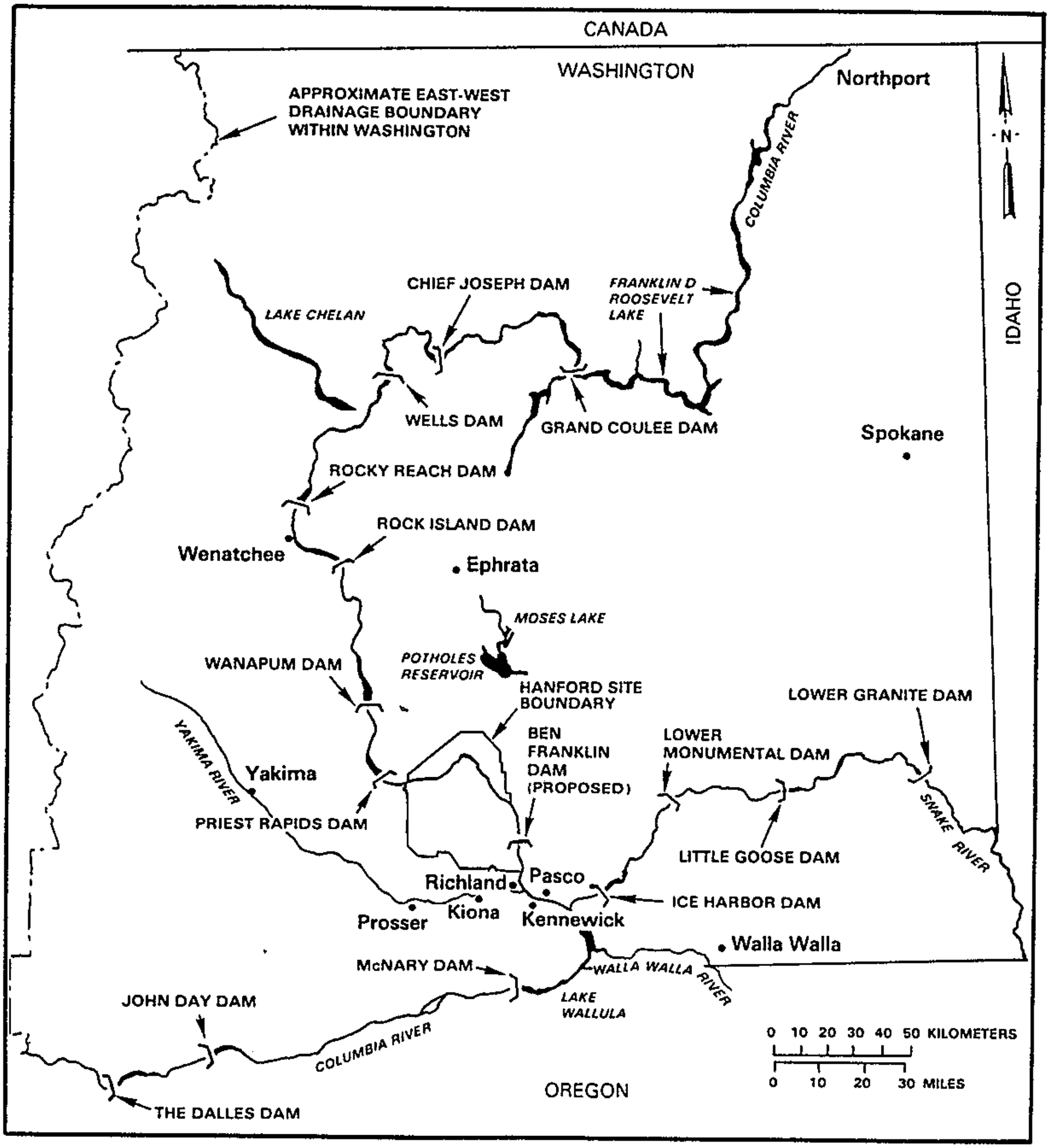

FIGURE 4.2-7. Locations of Principal Dams Within the Columbia Plateau Study Area (DOE 1988)

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second (cfs)] during the runoff in spring and early summer, to 1,000 to 4,500 cms during the low flow period of late summer and winter (Jamison 1982). The average annual Columbia River flow in the Hanford Reach, based on 65 years of record, is about 3,400 cms (120,100 cfs) (DOE 1988). A minimum flow of about 1,020 cms (35,000 cfs) is maintained along the Hanford Site. Normal river elevations within the Site range from 120 m (394 ft) above mean sea level where the river enters the Site near Vernita to 104 m (341 ft) where it leaves the Site near the 300 Area.

The Yakima River, bordering the southern portion of the Hanford Site, has a low annual flow compared to the Columbia River. For 57 years of record, the average annual flow of the Yakima River is about 104 cms (3673 cfs) with monthly maximum and minimum flows of 490 cms and 4.6 cms, respectively.

Cold Creek and its tributary, Dry Creek, are ephemeral streams within the Yakima River drainage system along the southern boundary of the Hanford Site. Both streams drain areas to the west of the Hanford Site and cross the southwestern part of the Site toward the Yakima River. Surface flow, when it occurs, infiltrates and disappears into the surface sediments in the western part of the Site. Rattlesnake Springs, located on the western part of the Site, forms a small surface stream that flows for about 3 km (1.8 mi) before disappearing into the ground. Approximately one-third of the Hanford Site is drained by the Yakima River system.

Total estimated precipitation over the Pasco Basin is about 9×10^8 m^3 annually, averaging less than 20 cm/yr (~8 in./yr). Mean annual runoff from the basin is estimated to be less than 3.1×10^7 m^3/yr, or approximately 3% of the total precipitation. The basin-wide runoff coefficient is zero for all practical purposes. The remaining precipitation is assumed to be lost through evapotranspiration, with a small component (perhaps less than 1%) recharging the groundwater system (DOE 1988).

Water use in the Pasco Basin is primarily from surface diversion with groundwater diversions accounting for less than 10% of the use. A listing of surface water diversions, volumes, types of usage, and populations served is given in DOE (1988). Industrial and agricultural usage represent about 32% and 58%, respectively, and municipal use about 9%. The Hanford Site uses about 81% of the water withdrawn for industrial purposes. However, because of the N-Reactor shutdown, and considering the data in DOE (1988), these percentages now approximate 13% industrial, 75% agricultural, and 12% for municipal use, with the Hanford Site accounting for about 41% of the water withdrawn for industrial use.

Approximately 50% of the wells in the Pasco Basin are for domestic use and are generally shallow [less than 150 m (500 ft)]. Agricultural wells, used for irrigation and stock supply, make up the second-largest category of well use, about 24% for the Pasco Basin. Industrial users account for only about 3% of the wells (DOE 1988).

Most of the water used by the Hanford Site is withdrawn from the Columbia River. The principal users of groundwater within the Hanford Site are the Fast Test Flux Facility, with a 1988 use of 142,000 m^3 from two wells in the unconfined aquifer, and the PNL Observatory, with a water supply from a spring on the side of Rattlesnake Mountain.

Regional effects of water use activities are apparent in some areas where the local water tables or potentiometric levels have declined because of withdrawals from wells. In other areas, water levels in the shallow aquifers have risen because of artificial recharge mechanisms such as excessive application of imported irrigation water or impoundment of streams. Wastewater ponds on the Hanford Site have artificially recharged the unconfined aquifer below the 200-East and 200-West Areas. The increase in water table elevations was most rapid from 1950 to 1960, and apparently had nearly reached equilibrium between the unconfined aquifer and the recharge during 1970 to 1980 when only small increases in water table elevations occurred. Wastewater discharges from the 200-West Area were significantly reduced in 1984 (DOE 1988), with an accompanying decline in water table elevations.

Groundwater

The regional geohydrologic setting of the Pasco Basin is based on the stratigraphic framework consisting of 1) numerous Miocene tholeiitic flood basalts of the Columbia River Basalt Group; 2) relatively minor amounts of intercalated fluvial and volcanoclastic Ellensburg Formation sediments; and

3) fluvial, lacustrine, and glaciofluvial suprabasalt sediments. Lateral groundwater movement is known to occur within a shallow, unconfined aquifer consisting of fluvial and lacustrine sediments lying on top of the basalts, and within deeper confined-to-semiconfined aquifers consisting of basalt flow tops, flow bottom zones, and sedimentary interbeds (DOE 1988). These deeper aquifers are intercalated with aquitards consisting of basalt flow interiors. Vertical flow and leakage between geohydrologic units is inferred and estimated from water level or potentiometric surface data but is not quantified, and direct measurements are not available (DOE 1988).

The multiaquifer system within the Pasco Basin has been conceptualized as consisting of four geohydrologic units: 1) the Grande Ronde Basalt; 2) Wanapum Basalt; 3) Saddle Mountain Basalt; and 4) suprabasalt Hanford and Ringold Formation sediments. Geohydrologic units older than the Grande Ronde Basalt are probably of minor importance to the regional hydrologic dynamics and system.

The Grande Ronde Basalt is the most voluminous and widely spread formation within the Columbia River Basalt Group and has a thickness of at least 2745 m (9000 ft). The Grande Ronde Basalt geohydrologic unit is composed of the Grande Ronde Basalt and minor intercalated sediments equivalent to or part of the Ellensburg Formation (DOE 1988). More than 50 flows of Grand Ronde Basalt underlie the Pasco Basin, but little is known of the lower 80% to 90% of this geohyrologic unit. This unit is a confined-to-semiconfined flow system that is recharged along the margins of the Columbia Plateau where the unit is at or close to the land surface, and by surface-water and groundwater inflow from lands adjoining the plateau. Vertical movement into and out of the unit is known to occur. Groundwater within the unit in the eastern Pasco Basin is believed to be derived from groundwater inflow from the east and northeast.

The Wanapum Basalt geohydrologic unit consists of basalt flows of the Wanapum Basalt intercalated with minor and discontinuous sedimentary interbeds of the Ellensburg Formation or equivalent sediments. In the Pasco Basin the Wanapum Basalt consists of three members, each consisting of multiple flows. The geohydrologic unit underlies the entire Pasco Basin and has a maximum thickness of 370 m (1215 ft). Groundwater within the Wanapum Basalt geohydrologic unit is confined to semiconfined. Recharge is believed to occur from precipitation where the Wanapum Basalt is not overlain by great thicknesses of younger basalt, leakage from adjoining formations, and surface-water and groundwater inflow from lands adjoining the plateau. Local recharge is derived from irrigation. Within the Pasco Basin recharge occurs along the anticlinal ridges to the north and west, with recharge in the eastern basin being from groundwater inflow from the east and northeast (DOE 1988). Interbasin transfer and vertical leakage are also believed to contribute to the recharge.

The Saddle Mountains Basalt geohydrologic unit is composed of the youngest formation of the Columbia River Basalt Group and several thick sedimentary beds of the Ellensburg Formation or equivalent sediments that comprise up to 25% of the unit. Within the Pasco Basin the Saddle Mountains Basalt contains seven members, each with one or more flows. This geohydrologic unit underlies most of the Pasco Basin, attaining a thickness of about 290 m (950 ft), but is absent along the northwest part of the basin and along some anticlinal ridges. Groundwater in the Saddle Mountains geohydrologic unit is confined to semiconfined, with recharge and discharge believed to be local (DOE 1988).

The rock materials that overlie the basalts in the structural and topographic basins within the Columbia Plateau generally consist of Miocene-Pliocene sediments, volcanics, Pleistocene sediments including those from catastrophic flooding, and Holocene sediments consisting mainly of alluvium and eolian deposits. The suprabasalt geohydrologic unit (referred to as the Hanford/Ringold unit) consists principally of the Miocene-Pliocene Ringold Formation stream, lake, and alluvial materials, and the Pleistocene catastrophic flood deposits informally called the Hanford formation. Groundwater within the suprabasalt geohydrologic unit is generally unconfined, with recharge and discharge usually coincident with topographic highs and lows (DOE 1988). The Hanford/Ringold unit is essentially restricted to the Pasco Basin with principal recharge occurring along the periphery of the basin from precipitation and ephemeral streams.

Little if any natural recharge occurs within the Hanford Site, but artificial recharge occurs from liquid waste disposal activities. Recharge from irrigation occurs east and north of the Columbia River and in the synclinal valleys west of the Hanford Site. Upward leakage from lower aquifers into the unconfined aquifer is believed to occur in the northern and eastern sections of the Hanford Site. Groundwater discharge is primarily to the Columbia River.

Groundwater under the Hanford Site occurs under unconfined and confined conditions. The unconfined aquifer is contained within the glaciofluvial sands and gravels and within the Ringold Formation. It is dominated by the middle member of the Ringold Formation, consisting of sorted sands and gravels of varying hardness. The bottom of the aquifer is the basalt surface or, in some areas, the clay zones of the lower member of the Ringold Formation. The confined aquifers consist of sedimentary interbeds and/or interflow zones that occur between dense basalt flows in the Columbia River Basalt Group. The main water-bearing portions of the interflow zones occur within a network of interconnecting vesicles and fractures of the flow tops or flow bottoms.

Sources of natural recharge to the unconfined aquifer are rainfall and runoff from the higher bordering elevations, water infiltrating from small ephemeral streams, and river water along influent reaches of the Yakima and Columbia rivers. The movement of precipitation through the unsaturated (vadose) zone has been studied at several locations on the Hanford Site to define the movement of water in the vadose zone. Conclusions from these studies are varied depending on the location studied. Some investigators conclude that no downward percolation of precipitation occurs on the 200-Area Plateau where soil texture is varied and is layered with depth, and that all moisture penetrating the soil is removed by evaporation. Others have observed downward water movement below the root zone in tests conducted near the 300 Area, where soils are coarse textured and precipitation was above normal (DOE 1987).

From the recharge areas to the west, the groundwater flows downgradient to the discharge areas, primarily along the Columbia River. This general west-to-east flow pattern is interrupted locally by the groundwater mounds in the 200 Areas. From the 200 Areas, there is also a component of groundwater flow to the north, between Gable Mountain and Gable Butte. These flow directions represent current conditions; the aquifer is dynamic, and responds to changes in natural and artificial recharge.

Local recharge to the shallow basalts is believed to result from infiltration of precipitation and runoff along the margins of the Pasco Basin. Regional recharge of the deep basalts is thought to result from interbasin groundwater movement originating northeast and northwest of the Pasco Basin in areas where the Wanapum and Grande Ronde Basalts crop out extensively (DOE 1986). Groundwater discharge from the shallow basalt is probably to the overlying unconfined aquifer and the Columbia River. The discharge area(s) for the deep groundwaters is presently uncertain, but flow is believed to be generally southeastward with discharge speculated to be south of the Hanford Site (DOE 1986).

4.2.5 Flooding

Large Columbia River floods have occurred in the past (DOE 1987), but the likelihood of recurrence of large-scale flooding has been reduced by the construction of several flood control/water storage dams upstream of the Site. Major floods on the Columbia River are typically the result of rapid melting of the winter snowpack over a wide area augmented by above-normal precipitation. The maximum historical flood on record occurred June 7, 1894, with a peak discharge at the Hanford Site of 21,000 cms (742,000 cfs). The flood plain associated with the 1894 flood is shown in Figure 4.2-8. The largest recent flood took place in 1948 with an observed peak discharge of 20,000 cms (706,280 cfs) at the Hanford Site. The probability of flooding at the magnitude of the 1894 and 1948 floods has been greatly reduced because of upstream regulation by dams (see Figure 4.2-7).

There have been fewer than 20 major floods on the Yakima River since 1862 (DOE 1986). The most severe occurred in November 1906, December 1933, and May 1948; discharge magnitudes at Kiona, Washington, were 1,870, 1,900, and 1,050 cms (66,000, 67,000, and 37,000 cfs, respectively. The recurrence intervals for the 1933 and 1948 floods are estimated at 170 and 33 years, respectively. The development of irrigation reservoirs within the Yakima

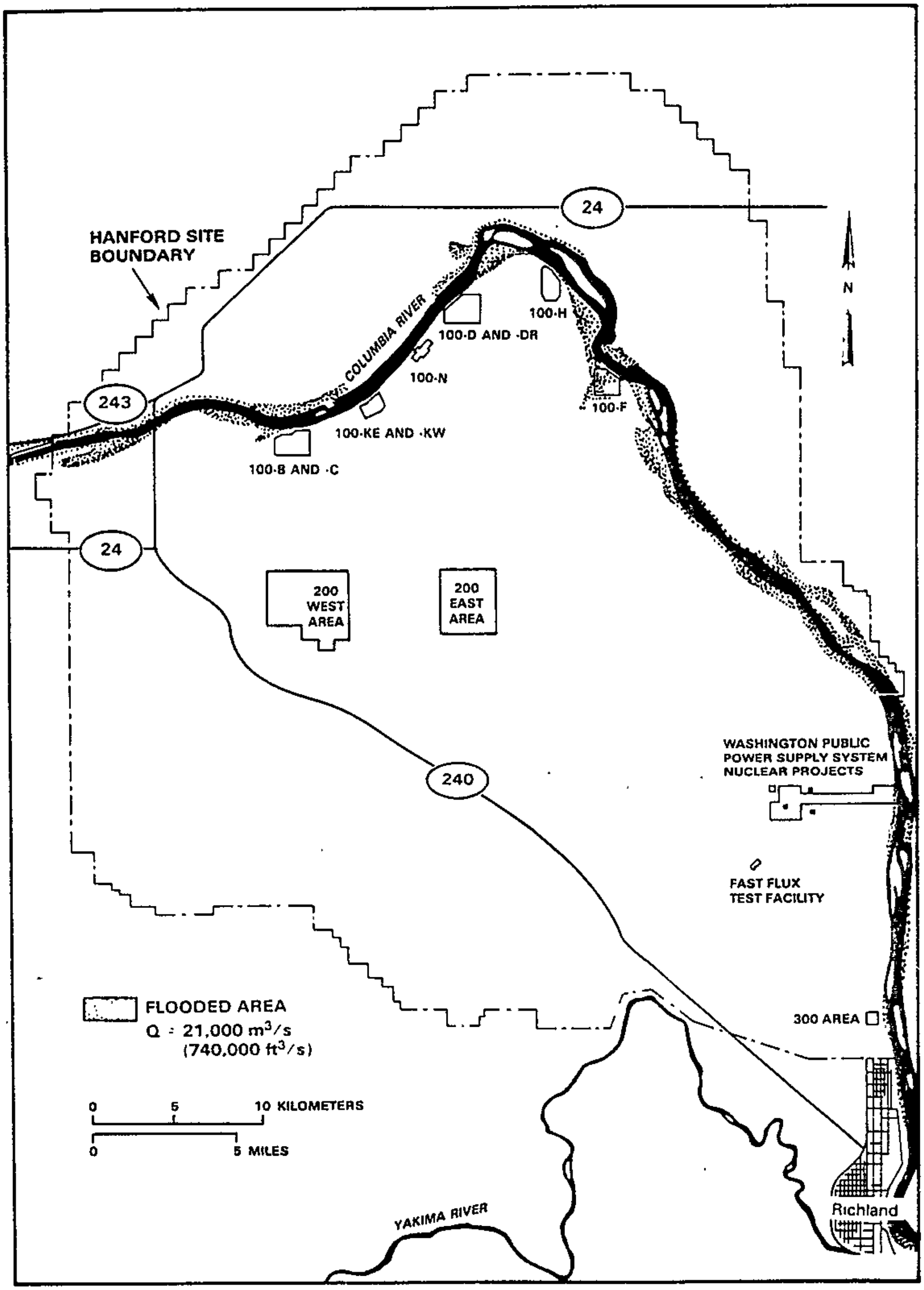

FIGURE 4.2-8. Flood Area During the 1894 Flood (DOE 1986)

River Basin has considerably reduced the flood potential of the river. Lands susceptible to a 100-year flood on the Yakima River are shown in Figure 4.2-9. Flooded areas could extend into the southern section of the Hanford Site, but the upstream Yakima River is physically separated from the Hanford Site by Rattlesnake Mountain, which would prevent major flooding of the Hanford Site.

Evaluation of flood potential is conducted in part through the concept of the probable maximum flood, which is determined from the upper limit of precipitation falling on a drainage area and other hydrologic factors, such as antecedent moisture conditions, snowmelt, and tributary conditions, that could result in maximum runoff. The probable maximum flood for the Columbia River below Priest Rapids Dam has been calculated to be 40,000 cms (1.4 million cfs). The flood plain associated with the probable maximum flood is shown in Figure 4.2-10. This flood would inundate parts of the 100 Areas located adjacent to the Columbia River, but the central portion of the Hanford Site would remain unaffected (DOE 1986).

Potential dam failures on the Columbia River have been evaluated. Upstream failures could arise from a number of causes, with the magnitude of the resulting flood depending on the degree of breaching at the dam. The U.S. Army Corps of Engineers evaluated a number of scenarios on the effects of failures of Grand Coulee Dam, assuming flow conditions of the order of 11,000 cms (400,000 cfs). The discharge resulting from a 50% breach at the outfall of Grand Coulee Dam was determined to be 600,000 cms (21 million cfs). In addition to the areas inundated by the probable maximum flood, the remainder of the 100 Areas, the 300 Area, and nearly all of Richland, Washington, would be flooded (DOE 1986). No determinations were made for breaches greater than 50% of Grand Coulee, for failures of dams upstream, or for associated failures downstream of Grand Coulee. The 50% scenario was believed to represent the largest realistically conceivable flow resulting from a natural or human-induced breach (DOE 1986).

The possibility of a landslide resulting in river blockage and flooding along the Columbia River has also been examined for an area bordering the east side of the river upstream from the city of Richland. The possible landslide area considered was the 75-m- (250-ft-) high bluff generally known as White

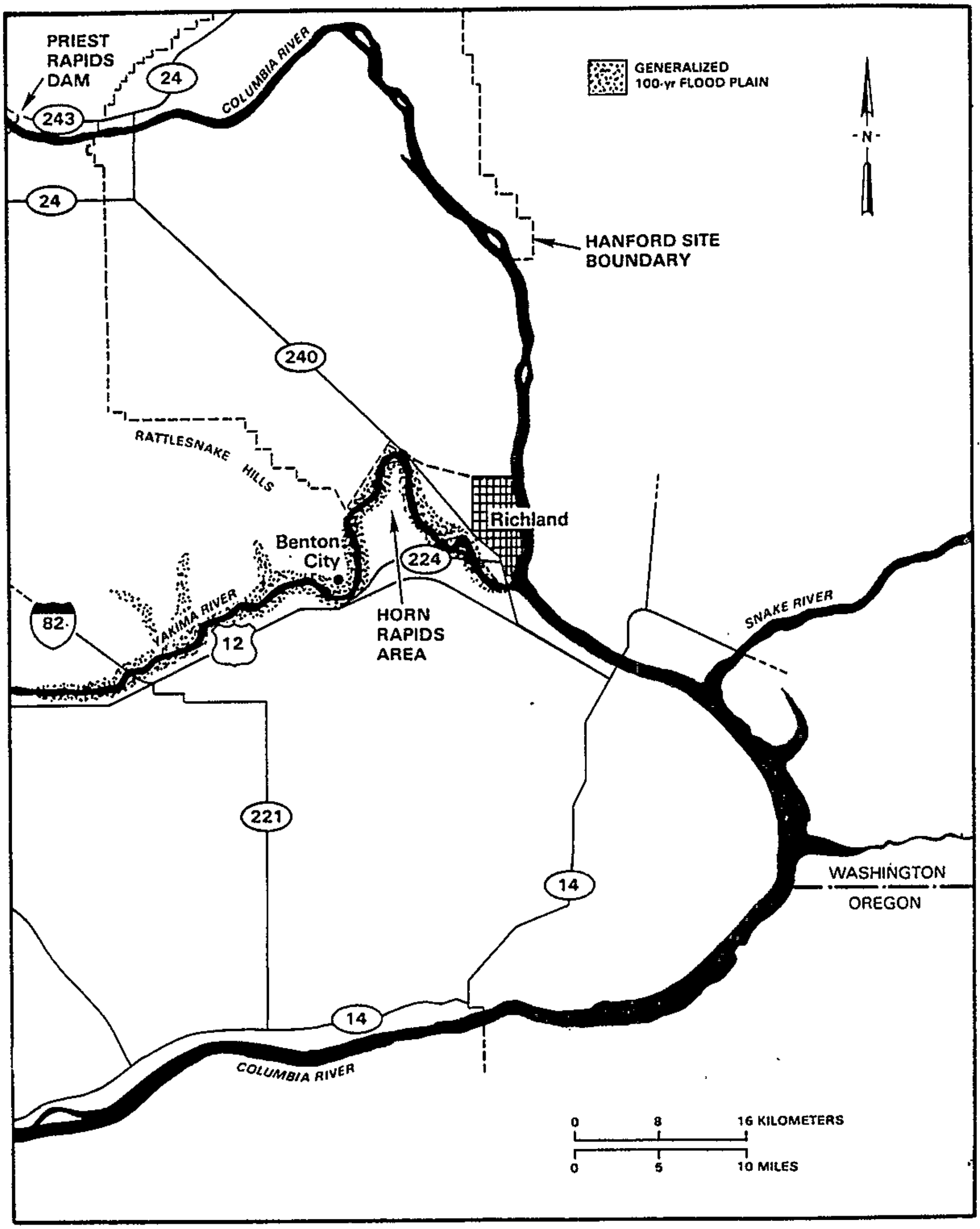

FIGURE 4.2-9. Flood Area from a 100-Year Flood of the Yakima River in the Vicinity of the Hanford Site (DOE 1986)

9 3 1 2 9 5 4 0 0 6 5

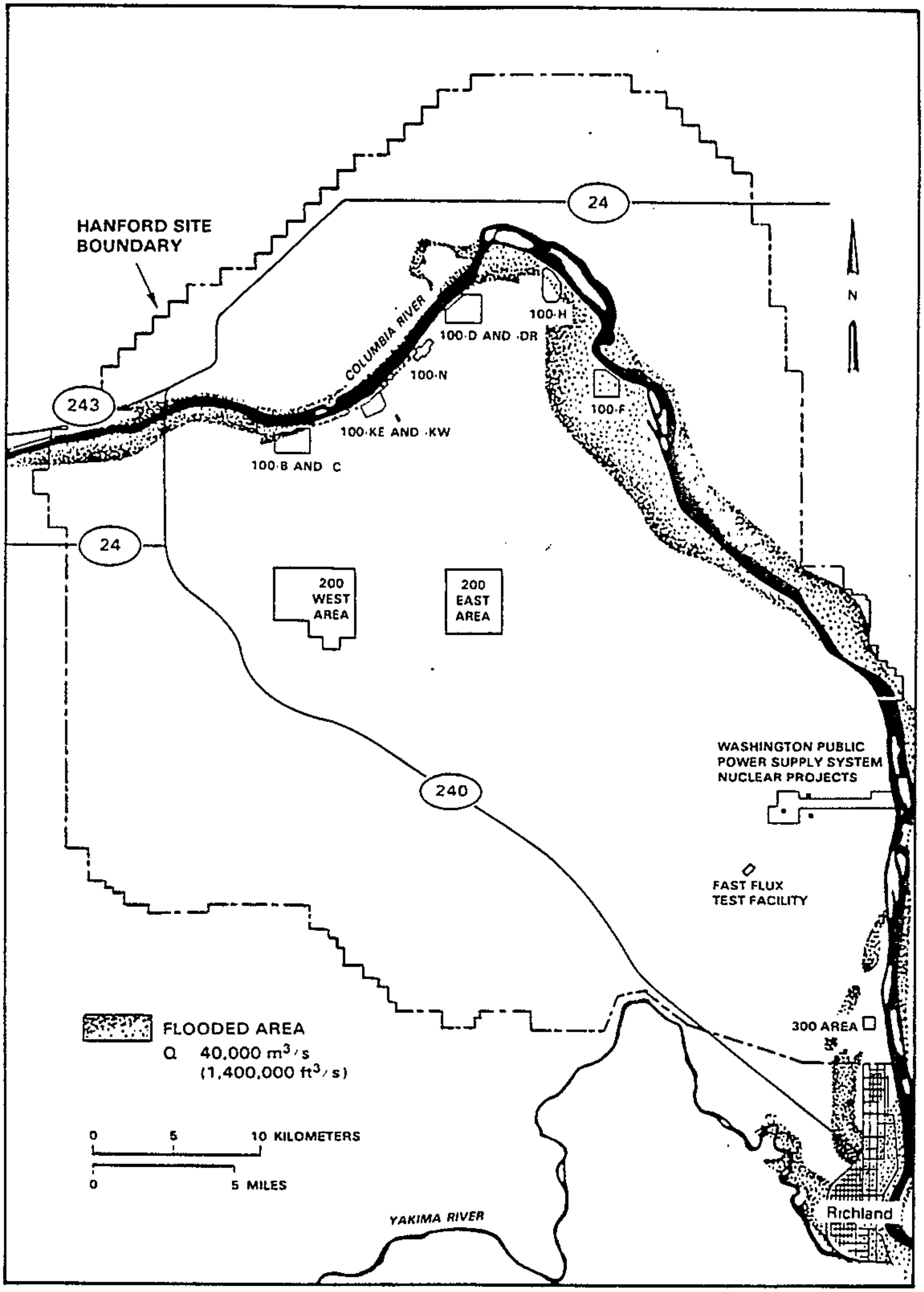

FIGURE 4.2-10. Flood Area for the Probable Maximum Flood (DOE 1986)

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Bluffs. Calculations were made for an 8×10^5 m^3 (1×10^6 yd^3) landslide volume with a concurrent flood flow of 17,000 cms (600,000 cfs) (a 200-year flood) resulting in a flood wave crest elevation of 122 m (400 ft) above mean sea level. Areas inundated upstream from such a landslide event would be similar to those shown in Figure 4.2-10 (DOE 1986).

4.2.6 Water Quality

Columbia River

The State of Washington Department of Ecology classifies the Columbia River as Class A (excellent) between Grand Coulee Dam and the mouth of the river near Astoria, Oregon (DOE 1986). The Class A designation requires that industrial uses of this water be compatible with other uses, including drinking water, wildlife, and recreation (PNL 1988). The Hanford Reach of the Columbia River is the last free-flowing portion of the river in the United States.

The PNL conducts routine monitoring of the Columbia River for both radiological and nonradiological water quality parameters. A yearly summary of results has been published since 1973 (PNL 1988). Numerous other water quality studies have been conducted on the Columbia River relative to the impact of the Hanford Site over the past 37 years. The DOE currently holds a National Pollutant Discharge Elimination System (NPDES) permit for eight effluent discharges into the Columbia River.

Radiological monitoring shows low levels of radionuclides in samples of Columbia River water. Hydrogen-3 (tritium), iodine-129, and uranium are found in slightly higher concentrations downstream of the Hanford Site than upstream (PNL 1988), but were well below concentration guidelines established by the U.S. Department of Energy and the U.S. Environmental Protection Agency drinking-water standards. Cobalt-60 and iodine-131 were not consistently found in measurable quantities during 1987 in samples of Columbia River water from Priest Rapids Dam, the 300-Area water intake, or the Richland city pumphouse (PNL 1988). The average annual strontium-90 concentrations were essentially the same at Priest Rapids Dam and the Richland Pumphouse for 1987 (PNL 1988).

Nonradiological water quality parameters measured during 1987 were similar to those reported in previous years and were within Washington State Water Quality Standards (DOE 1988). Discharge of nonradioactive water is made to the Columbia River from eight outfalls under an EPA permit issued to DOE Richland Operations Office and regulated by the NPDES. Five of the outfalls are located at the 100-N Area, two at the 100-K Area, and one at the 300 Area (UNI 1987).

Unconfined Aquifer

As part of the continuing environmental monitoring program, groundwater monitoring reports have been issued since 1956 and are now published in the Hanford Site Environmental Report, which is issued by calendar year. The shallow, unconfined aquifer in the Pasco Basin and on the Hanford Site contains waters of a dilute (less than or approximately 350 mg/L total dissolved solids) calcium bicarbonate chemical type. Other principal constituents include sulfate, silica, magnesium, and nitrate. Variability in chemical composition exists within the unconfined aquifer in part because of natural variation in the composition of the aquifer material; in part because of agricultural and irrigation practices north, east, and west of the Hanford Site; and, on the Hanford Site, in part because of liquid waste disposal.

Graham et al. (1981) compared analyses of unconfined aquifer water samples taken by the U.S. Geological Survey (USGS) in the Pasco Basin but off the Hanford Site with samples taken by PNL and the USGS on the Hanford Site for the years 1974-1979. In general, Hanford Site groundwater analyses showed higher levels of chemical constituents and temperatures than were reflected in the analyses of offsite samples.

Elevated levels of some constituents in the Hanford groundwater result from releases from various liquid waste disposal facilities. Nitrate, tritium, and total beta contamination have migrated away from these sites in a general west-to-east direction. Some longer lived radionuclides such as strontium-90 and cesium-137 have reached the groundwater, primarily through liquid waste disposal cribs. Minor quantities of longer lived radionuclides have reached the water table via a failed groundwater monitoring well casing, and through reverse well injection, a disposal practice that was discontinued at Hanford in 1947 (Smith 1980). The occurrence and consequences of leaks from waste storage tanks and the occurrence of radioactive materials in soils have been described elsewhere (ERDA 1975). These occurrences have not resulted, and are not expected to result, in radiation exposure to the public (ERDA 1975; DOE 1987).

Radioactive and nonradioactive effluents are discharged to the environment from Westinghouse Hanford facilities in the 200 Area (Coony et al. 1988). These effluents, in general, are discharged to the soil column. Cooling water represents by far the largest volume of potentially radioactive liquid effluent. Additional treatment systems for these effluents are being designed and installed pursuant to the schedule set forth in the Hanford Federal Facility Agreement and Consent Order, which was jointly issued by the DOE, the EPA, and the Washington State Department of Ecology in May 1989. Under the provisions of the Comprehensive Environmental Response Compensation and Liability Act (CERCLA), Remedial Investigations/Feasibility Studies (RI/FS) will be conducted for groundwater operable units at Hanford.

Springs are common on basalt ridges surrounding the Pasco Basin. Geochemically, spring waters are of a calcium- or sodium bicarbonate type with low dissolved solids (approximately 200 to 400 mg/L) (DOE 1986). Compositionally these waters are similar to shallow local groundwaters (unconfined aquifer and upper Saddle Mountains Basalt). However, they are readily distinguishable from waters of the lower Saddle Mountains (Mabton interbed) and the Wanapum and Grande Ronde Basalts, which are of sodium bicarbonate to sodium chloride bicarbonate (or sodium chloride sulfate) type. Currently there is no evidence suggesting that these spring waters contain any significant component of deeper groundwater.

Confined Aquifers

Areal and stratigraphic changes in groundwater chemistry characterize basalt groundwaters beneath the Hanford Site (Graham et al. 1981). The stratigraphic position of these changes is believed to delineate flow-system boundaries, and to identify chemical evolution taking place along groundwater flow paths. Some potential mixing of groundwaters has also been located using these data. The rate of mixing is unknown at present.

Overall, waters of the shallow basalts are of a sodium bicarbonate chemical type; those of the deep basalts are of a sodium chloride chemical type (DOE 1986). On a location-by-location basis, chemical and isotopic shifts can be pronounced (DOE 1982). The stratigraphic boundaries separating chemical types vary depending on location. At the reference repository location, groundwater composition was found to change systematically as a function of depth (DOE 1986).

Iodine-129 and tritium have been detected in confined groundwater zones in the Saddle Mountains Basalt beneath the Hanford Site (DOE 1986). Two areas have above-background concentrations of iodine-129. These areas are in the vicinity of West Lake and Gable Mountain Pond, and at one borehole located near the horn of the Yakima River.

4.2.7 Environmental Monitoring

The DOE has conducted an environmental monitoring program at the Hanford Site for the past 45 years. The monitoring results have been recorded since 1946 in quarterly reports. Since 1958, the results have been available as annual reports (summarized by Soldat et al. 1986). For calendar year 1989, the monitoring results for offsite and onsite environs and for onsite groundwater are combined in one PNL report (PNL 1990).

Radioactive materials in air were sampled continuously on the Hanford Site, at the Hanford Site perimeter, and in nearby and distant communities in the Columbia Basin in a total of 53 locations. No sample collected at the Hanford Site perimeter or in surrounding communities exceeds 0.1% of the applicable DOE Derived Concentration Guides (PNL 1990).

Groundwater was collected from 567 wells in 1989 that sample both the confined and unconfined aquifers beneath the Hanford Site. The major plume of tritium-contaminated groundwater continued to move eastward, resulting in seepage into the Columbia River. Samples of Columbia River water were collected immediately upstream and downstream from the Hanford Site. Concentrations of all radionuclides observed in river water were all well below applicable EPA and state of Washington drinking-water standards (PNL 1990).

Foodstuffs from the area, including those irrigated with Columbia River water, were sampled. All results were similar to the low concentrations found in foodstuffs grown in other adjacent areas, indicating no measurable impact as a result of Hanford operations.

Deer, rabbits, game birds, waterfowl, and fish were also collected and analyzed. Game birds, waterfowl, fish, and deer showed low levels of cesium-137 attributable to Hanford operations. Other concentrations of radionuclides were typical of levels attributable to worldwide weapon-test fallout.

Low concentrations of radionuclides were measured in onsite and offsite samples of soil and vegetation during 1989. The levels were similar to those obtained in previous years, and no discernible increase in the concentration could be attributed to current Hanford operations. Dose rates from external penetrating radiation measured in the vicinity of local residential areas were similar to those observed in previous years, and no contribution from Hanford activities could be identified.

Certain chemicals for which Drinking Water Standards have been set by the EPA and the state of Washington were also present in Hanford groundwater near operating areas. Nitrate concentrations exceeded the drinking-water standards (DWS) at isolated locations in the 100, 200, and 300 Areas and in several 600-Area locations. Chromium concentrations were above the DWS at the 100-D, 100-H, and 100-K Areas, and the surrounding areas. Chromium concentrations above the DWS were also found in the 200-East and 200-West Areas. Cyanide was detected in groundwater north of the 200-East Area. High concentrations of carbon tectrachloride were found in wells in the 200-West Area. Trichloroethylene was found at levels exceeding the DWS at wells in and near the 100-F Area, 300 Area, and Solid Waste Landfill. Sampling at monitoring wells near Richland water supply wells showed that concentrations of regulated groundwater constituents in this area are below DWS and in general below detection levels.

Measured and calculated radiation doses to the general public from Hanford operations were well below applicable regulatory limits throughout 1989. The potential effective dose equivalent received by a hypothetical maximally exposed individual from 1989 operations was about 0.05 millirem. This is a decrease of 0.03 millirem from the value reported for 1988. The population effective dose to the local population of 340,000 persons was 1 person-rem, as compared with 5 person-rem in 1988.

These doses are much less than doses potentially received by the general public from other common sources of radiation (Figure 4.2-11). The calculated effective dose equivalent using the new DOE Radiation Standards for the Protection of the Public was 0.004 millirem for 1989, compared with the limits of 100 millirem per year for prolonged exposure and 500 millirem per year for occasional annual exposure to a maximally exposed individual (PNL 1990).

4.2.8 100 Areas

The geologic units beneath the 100 Areas can be divided into three distinct units: the Columbia River Basalt, the Ringold Formation, and the glaciofluvial sediments (Figure 4.2-12). The Columbia River Basalt is

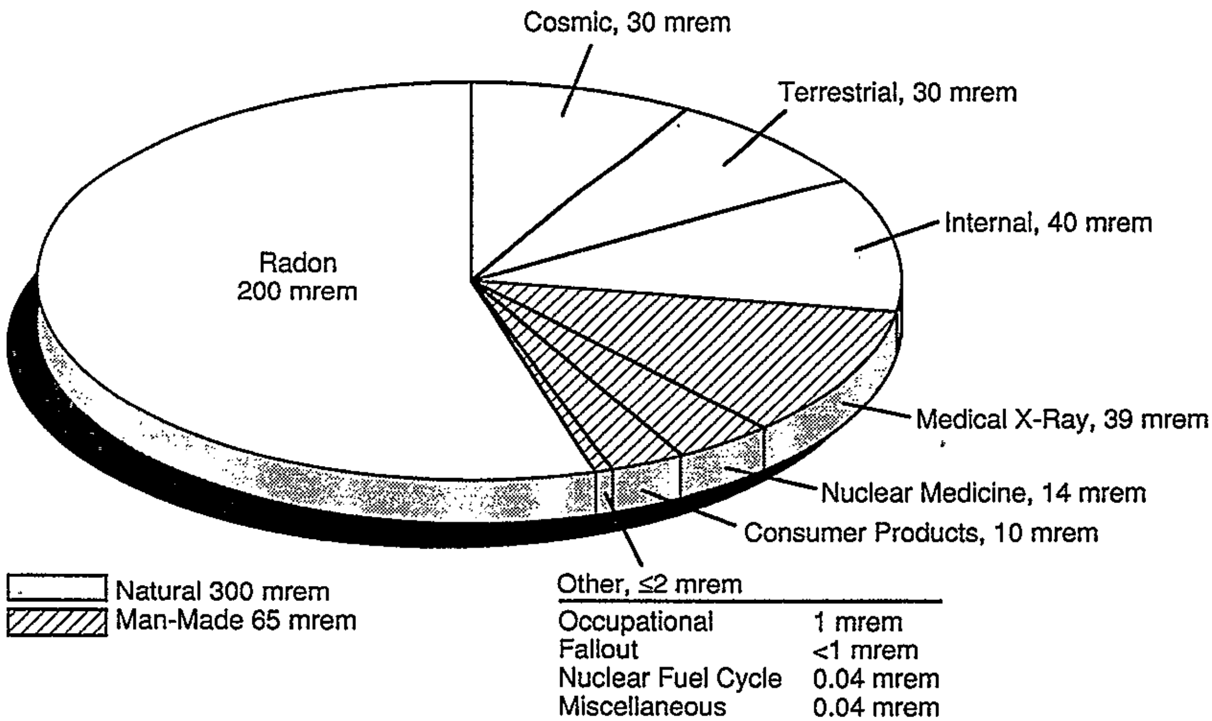

FIGURE 4.2-11. Annual Radiation Doses from Various Sources (NCRP 1987)

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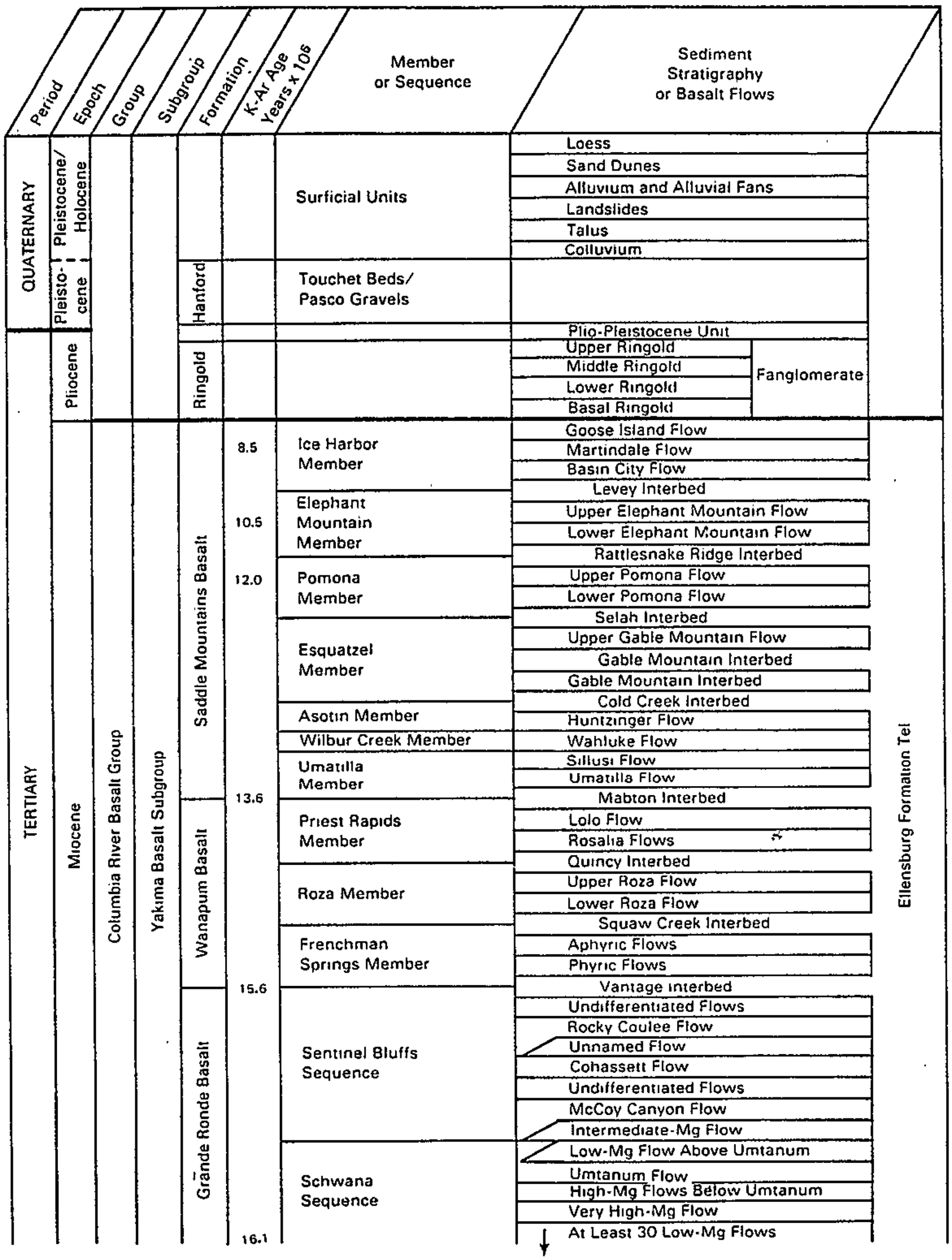


FIGURE 4.2-12. Stratigraphic Units Present in the Pasco Basin (DOE 1986)

compact, dense, and hard lava, and forms the bedrock in the 100 Areas. The surface of the basalt generally reflects the structure of the basalt series and is only locally modified by erosion (Brown 1962).

In the western part of the 100 Areas, near the B and K sites, the upper approximately 30 m (107 ft) of basalt is essentially continuous without significant interbeds. To the east, near the H and F sites, there are numerous interbeds within the upper portion of the basalts. The interbed materials are predominantly sand, gravel, clay, and volcanic ash. Some of these interbeds may be correlative with the Pliocene-age Ellensburg Formation of central Washington. Drill cuttings from some wells have shown that the upper surface of the basalt may be vesicular to scoriaceous, caused by escape of gases during cooling of the basalt lava. Samples from deeper than about 3 m (10 ft) below the surface of the basalt are generally hard, dense, fine textured, and dark gray.

Overlying the basalt bedrock are the clays, silts, sands and gravels of the Ringold Formation. Various members of the Ringold Formation are distinguishable over much of the Hanford Site, but within the 100 Areas the various members are not as clearly distinct from each other and are not readily differentiated. In the northwestern part of the Hanford Site, the Ringold Formation generally is dominantly coarse material such as sands and gravels; farther to the east it grades into sand and coarse silt, and on the eastern margin is mostly silt and clay. The upper portion of the Ringold Formation is probably absent beneath most of the reactor areas because of erosion, but within the 100 Areas the Ringold is as thick as about 185 m (60 ft) (Brown 1962). Extensive portions of the middle part of the Ringold Formation contain sand and gravels thoroughly cemented with calcium carbonate, making them highly resistant to erosion. One of the prime examples is in the Columbia River channel near K Area.

Glaciofluvial sediments consisting of sand, gravel, and boulders with occasional lenses of fine, well-sorted materials overlie the eroded Ringold surface in the 100 Areas. Areas of hummocky topography, believed to be associated with the disintegrating ice mass to the north and with melting icebergs, are found in the K and D areas. There are also areas where wind has reworked the finer outwash material and formed sand dunes and well-sorted beds of sandy silt. The glaciofluvial materials are as much as about 50 m (164 ft) thick in the 100 Areas.

The water table, representing the upper boundary of the unconfined groundwater, varies in depth beneath the 100 Areas from 10 m (33 ft) or less to about 30 m (107 ft) with an average depth of about 20 m (66 ft) (McGhan et al. 1985). Recharge is generally from the highland areas to the south and southwest, and flow is in general toward the Columbia River.

The vertical permeability of the basalt flows is relatively low, particularly when compared to the horizontal permeability of the interflow zones. The groundwater within the basalt series is quite separate and distinct from that in the postbasalt sediments. The Ringold material directly overlying the basalt is of relatively low permeability, while the glaciofluvial material overlying the Ringold may have permeabilities several orders of magnitude higher.

Tracer tests have shown that the groundwater moves at relatively high velocities through glaciofluvial sediments deposited in eroded channels in the Ringold surface. Several of these channels are known to occur in the 100 Areas. One of the most prominent is located just north of Gable Mountain.

4.2.9 200 Areas

The Separations Areas (200 Areas), located near the center of the Hanford Site, lie on a broad flood bar. This bar is commonly referred to as the 200-Area Plateau. Operations in this portion of the Hanford Site have resulted in the storage, disposal, and accidental release of radionuclides and other industrial wastes.

The major geologic units beneath the 200 Areas are, in ascending order, basement rocks of undetermined origin, the Columbia River Basalt Group with intercalated sediments of the Ellensburg Formation, the Ringold Formation, the Plio-Pleistocene unit, and the Hanford formation. The surface of the 200 Areas is veneered with loess and sand dunes of varying thickness.

The Columbia River Basalt Group is a thick sequence of tholeiitic basalts. This layered sequence is subdivided into five formations (Ledgerwood et al. 1978; Swanson et al. 1979). The upper three formations, the Grande Ronde Basalt, the Wanapum Basalt, and the Saddle Mountain Basalt, collectively constitute the Yakima Basalt Subgroup (Swanson et al. 1979). Beneath the Separations Areas, this basalt sequence is at least 1460 m (4,790 ft) thick and may be as much as 4267 m (14,000 ft) thick (Myers et al. 1979). Flows of the Columbia River Basalt Group are interbedded with and overlain by Miocene-Pliocene epiclastic and volcaniclastic sediments of the Ellensburg Formation (Myers et al. 1979).

The Ringold Formation is present throughout most of the 200 Areas, and has been divided into four textural units: 1) sand and gravel of the basal Ringold member; 2) clay, silt, and fine sand with minor gravel lenses of the lower Ringold member; 3) occasionally cemented sand and gravel of the middle Ringold member; and 4) silt and fine sand of the upper Ringold member (Brown 1959).

The silts and sands of the lower member were deposited in the still-forming synclinal depressions. This low-energy fluvial/lacustrine deposit is thickest in the Cold Creek syncline. The unit pinches out on the flanks of the Umtanum-Gable Mountain Structure where it apparently was not deposited.

The middle silty, sandy, gravel member is the thickest Ringold member beneath the Separation Areas. In general, the upper part of the middle Ringold is not indurated except for isolated cementation from calcium carbonate, while the lower part of the unit is moderately to well indurated.

The upper Ringold member is present only beneath parts of the 200-West Area. This silty sand member contains several caliche horizons indicating that the eroded surface of the unit was exposed to subaerial processes of a semiarid-to-arid environment comparable to that of the present day. The upper Ringold member apparently was completely stripped by erosional processes throughout the remainder of the Separation Areas.

The Plio-Pleistocene unit, an eolian silt and fine sand, overlies the Ringold Formation in the western part of the Hanford Site (Brown 1960).

Normal fluvial processes as well as Pleistocene catastrophic flooding apparently stripped much of the eolian deposit within the Separation Areas (Tallman et al. 1979).

The Hanford formation lies on the eroded surface of the Plio-Pleistocene unit, the Ringold Formation, and, locally, the basalt bedrock. These sediments have locally been divided into two main facies, termed the "Pasco gravels" facies and the "Touchet Beds" facies (Myers et al. 1979).

The Pasco Gravels facies (Tallman et al. 1979) is composed of poorly sorted, subrounded to angular clasts that commonly display fore-set bedding (Myers et al. 1979). These sediments indicate high-energy depositional environments. The Touchet Beds facies consists of rhythmically bedded sequences of graded silt, sand, and minor gravel units. These deposits are limited to areas where slack-water conditions occurred during the impoundment of flood waters behind the Wallula Gap constriction (Tallman et al. 1979; Myers et al. 1979). Eolian sediments consisting of both active and inactive sand dunes locally veneer the surface of the 200 Areas.

Depth to groundwater is about 75 m (246 ft) in the 200-East Area and about 50 to 60 m (164 to 197 ft) in the 200-West Area. Recharge to the 200 Areas, which are essentially in the center of the Hanford Site, is described under Hydrology (Subsection 4.2.4). Groundwater flow direction is generally in an easterly and southeasterly direction, toward the Columbia River.

Hydrogeology of the 200-West Area

The hydrogeologic units of principal interest are, in ascending order: the Pomona Member, a thick and dense basalt flow(s) that forms the base of the Rattlesnake Ridge aquifer; the Rattlesnake Ridge interbed, which forms the physical framework of the uppermost basalt aquifer; the Elephant Mountain Member, which forms the confining bed over the Rattlesnake Ridge aquifer; the Ringold Formation, which forms the framework of the locally confined basal Ringold aquifer and the unconfined aquifer; and the Plio-Pleistocene unit and Hanford formation, which form the framework of the unsaturated (vadose) zone.

The Pomona Member averages about 45 m thick beneath the 200-West Area, and thins to the northwest (Myers et al. 1979). Northeast of the site on

Gable Mountain, the Pomona displays for intraflow structures; a basal colonnade, and entablature, an upper colonnade, and a flow top (Fecht 1978). The interior of the Pomona is dense and exhibits very low permeability. Hydraulic conductivity of the Columbia River basalt flow interiors is extremely low, ranging from 10^{-6} to 10^{-8} m/day. However, flow tops of the Saddle Mountain Basalts typically have higher equivalent hydraulic conductivities, ranging from 10^{2} to 10^{-2} m/day.

The Rattlesnake Ridge interbed was deposited on the weathered surface of the Pomona. Its thickness averages about 27 m (about 89 ft). Locally, it has been divided into four facies on the basis of composition. These facies are, in ascending order: 1) a clayey basalt conglomerate formed by the weathering and reworking of the Pomona flow top; 2) an epiclastic fluvial-floodplain unit deposited by the ancestral Columbia River system; 3) a tuff made up of an air-fall ash; and 4) a tuffite derived from fluvial reworking of the tuff and epiclastic detritus (Graham et al. 1984). The tuff and tuffite units exhibit higher natural radioactivity (as indicated by natural gamma logs) and high glass content in borehole samples. These units remain relatively constant in grain size but vary in thickness. Grain size ranges from sandy gravel to sands and silts, which appear to interfinger and grade laterally into one another. The Rattlesnake Ridge interbed forms the uppermost, regionally extensive confined aquifer. The different lithologies produce some degree of anisotropy and heterogeneity within the aquifer.

The Elephant Mountain Member (10.5 mybp) is the uppermost and youngest basalt member beneath the 200-West Area. It is generally conformable to the surface of the Rattlesnake Ridge interbed, but in areas has been found to be invasive into the underlying sediments (Fecht 1978). The member consists of two flows or flow lobes. Only the lowermost flow (Elephant Mountain I) is present, averaging about 87 m (about 285 ft) in thickness. Fecht (1978) describes three intraflow structures in the lower flow. These are, in ascending order, colonnade, entablature, and flow top. The interior of the Elephant Mountain I flow is dense with very low hydraulic conductivities typical of the Columbia River Basalts. This low hydraulic conductivity acts to confine the Rattlesnake Ridge aquifer (Graham et al. 1984).

The Ringold Formation is present and continuous beneath the 200-West Area. Its thickness averages 120 m (394 ft) (Tallman et al. 1979), thickening to the southwest. All four textural units (basal, lower, middle, and upper) are present; only the upper Ringold is discontinuous.

The basal Ringold unit, the oldest and lowermost, directly overlies and is conformable to the Elephant Mountain Member. It averages about 15 m (50 ft) thick and thickens as it dips to the southwest. The basal Ringold is predominately a matrix- (sand-) supported gravel unit with stringers of coarse-to-fine sand and silt. Beneath the 200-West Area, where the basal Ringold is capped by the lower Ringold, it forms a confined aquifer.

The lower Ringold unit occurs throughout the site and averages approximately 15 m (50 ft) thick. The surface of the unit dips to the southwest where it also thickens. The texture of this unit ranges from a silty coarse-to-medium sand to sandy silt, generally becoming finer from north to south. Stringers of coarse-to-fine pebbles, up to 1 ft thick, are common. Also, fine pebbles are found scattered throughout beds within the unit. The lower Ringold has hydraulic conductivities of 1 to 1.36 m/day (3 to 5 ft/day) (Graham 1981) and serves to confine the basal Ringold aquifer.

The silty, sandy gravel of the middle Ringold unit is also present throughout the 200-West Area. This unit is the major constituent of the Ringold Formation, averaging about 90 m (295 ft) thick, thinning to the north and east. The unit consists of well-rounded pebbles and small cobbles with a matrix of coarse-to-fine sand and silt. The amount of cementation varies but generally is greatest in the lower part of the unit, where it is moderately to well indurated with calcium carbonate and/or silica. Silt and sand lenses up to 5 m (16 ft) thick are present within the conglomerate.

The sand, silt, and clay of the upper Ringold are present, but discontinuous beneath the 200-West Area. Where present, the thickness averages about 6 m (20 ft). The unit is composed of well-sorted sand and silt with minor lenses of fine pebbles. A caliche horizon often caps the upper Ringold. Other caliche horizons have been identified throughout the unit.

The Plio-Pleistocene unit lies unconformably on the upper and middle Ringold members beneath nearly all the 200-West Area. This unit, which resulted from the reworking and redeposition of the upper Ringold member sediment by wind, averages about 6 m thick. The sediments are typically fine grained, consisting predominantly of very fine sand and silt. A relatively high calcium carbonate content is present in the eolian silts, suggesting that the deposit contains reworked caliche from the upper Ringold member (Tallman et al. 1979).

The major surface and near-surface sand and gravel deposits in the 200-West Area are glaciofluvial sediments of the Hanford formation. The Hanford formation averages about 45 m (148 ft) thick and is composed of the Pasco Gravel facies. Beneath the 200-West Area, these sediments can be further broken down into three main units based on texture. The lowermost unit is a slightly silty medium to very fine sand that is present only in the southern half of the site and becomes finer to the south. The middle unit, a pebbly coarse-to-medium sand to slightly silty coarse-to-medium sand, is present throughout the 200-West Area, except for areas to the north and west. The unit averages about 25 m (82 ft) thick, and generally grades from coarse sediments in the northwest to finer sediments in the south and west. The uppermost textural unit of the Hanford formation in the 200-West Area is a silty sandy gravel to slightly silty, very coarse to coarse sand. This unit forms the surficial materials of the 200-West Area, except in the extreme south where it is not present or local deposits of eolian loess occur. As with the other Hanford units, these sediments also appear to become finer to the south.

<u>Hydrogeology of the 200-East Area</u>

Areas north and east of the 200-East Area (Gable Mountain Pond and B Pond) are incorporated into this description. The geologic units of principal interest are the same in the 200-East Area as they are in the 200-West Area. There are, however, some notable differences in the occurrence of specific units, and in the thickness and extent of those units.

The Pomona Member, which forms the base of the Rattlesnake Ridge aquifer, averages about 56 m (184 ft) thick beneath this portion of the Hanford

Site and thickens slightly to the south. On the western Gable Mountain anticline it is typified by four major intraflow structures: basal colonnade, entablature, upper colonnade, and flow top (Fecht 1978). The interior of the Pomona Member is dense and exhibits very low permeability.

The Rattlesnake Ridge interbed beneath the 200-East Area is equivalent to the unit under the 200-West Area as described. This unit is the uppermost, regionally extensive confined aquifer in the area. As beneath the 200-West Area, the varying lithologies produce some degree of anisotropy and heterogeneity affecting the flow of groundwater.

The Elephant Mountain Member (10.5 mybp) is the uppermost and youngest basalt member beneath this area, and is generally conformable to the surface of the Rattlesnake Ridge interbed. In some areas the Elephant Mountain has been found to be invasive into the underlying sediments (Fecht 1978). The basalt member consists of two flows or flow lobes. The lowermost flow (Elephant Mountain I) is continuous over most of this area, ranging in thickness from 35 to 11.5 m (115 to 38 ft) (where it is partially eroded away), thinning to about 6 m over Gable Mountain. Fecht (1978) describes three intraflow structures in the lower flow. These are, in ascending order: colonnade, entablature, and flow top. The upper flow (Elephant Mountain II) is present only in the southeast and northern portions of the area. This flow is roughly one-quarter the thickness of the Elephant Mountain I flow [averaging 7.7 m (25 ft)] and thickens to the southeast and north. An interflow zone separates the two flows. This interflow zone has interconnecting vesicles and rubbly zones.

The Elephant Mountain Member forms the bedrock surface beneath the area, except where it has been locally eroded, exposing the older units. Much of this erosion occurred during the deposition of Ringold sediments, as the ancestral Columbia River flowed through the structural low west of Gable Mountain (Graham et al. 1984). Further erosion occurred following deposition of the Ringold Formation, as Pleistocene catastrophic floods inundated the area. Both the Elephant Mountain I and II flows are dense, low permeability, basalt flows with very low hydraulic conductivities typical of the Columbia River Basalts.

The Ringold Formation is present beneath the site except at Gable Mountain where the formation was apparently not deposited, and in the area north of the 200-East Area, where mainstream currents of late Pleistocene flooding have completely removed it (Graham et al. 1984). The Ringold Formation averages approximately 60 m (197 ft) thick beneath the 200-East Area and 40 m thick beneath B Pond, and is absent beneath Gable Mountain Pond. All four textural units (basal, lower, middle, and upper) have been identified.

The basal Ringold directly overlies the Elephant Mountain Member. In the southern portion of the area, it is overlain by the lower Ringold and is well defined. In the central portion of the area, the lower Ringold apparently pinches out, making definition of the basal Ringold difficult because of its similarities to the now-overlying middle Ringold (Graham et al. 1984). The basal Ringold averages about 22 m thick (72 ft) and thickens to the south.

The lower Ringold ranges from silty coarse to medium sand to a sandy silt to clay (Tallman et al. 1979) and locally includes some gravel stringers. The lower Ringold sediments are generally compacted and exhibit a variety of degrees of induration.

The middle Ringold unit occurs throughout the area except over Gable Mountain and in the deeply eroded channels adjacent to Gable Mountain. Its thickness averages approximately 30 m (100 ft) in the southern part of the area, thinning toward the north and east. Erosion has modified the surface of the middle Ringold. Reworked portions are often difficult to differentiate from the undisturbed portions. The unit consists of well-rounded pebble- to cobble-size gravel with a matrix of sand, silt, and some clay. Induration of the unit ranges from virtually no cement to well cemented by calcium carbonate or silica. Consolidation of the unit ranges from matrix-supported conglomerate to open-work uncemented gravel (Tallman et al. 1979).

The upper Ringold is identified only near B Pond and consists of a fine to very fine sand, averaging about 3 m (10 ft) thick. The unit was likely not deposited on Gable Mountain, and elsewhere it has been eroded away.

Surface and near-surface deposits are of unconsolidated sand and gravel of the Hanford formation. The thickness of the Hanford formation averages about 60 m (197 ft), but thins to approximately 10 m (33 ft) beneath Gable Mountain Pond. The Hanford formation can be broken down into three main textural units beneath the 200-East Area.

The lowermost unit is a pebbly very coarse sand to sandy gravel that is relatively thin [approximately 10 m (33 ft)] and lies directly on the middle Ringold. This unit is present mostly beneath the southern and eastern portions of the area, possibly extending to beneath B Pond.

The middle textural unit is a coarse-to-fine sand unit. This unit is the thickest and most extensive Hanford formation unit in the vicinity. It averages about 60 m (197 ft) thick and is present throughout the 200-East Area, except in the northeastern portion where a main channel appears to cut through the unit (Tallman et al. 1979). The unit has a wide variation of grain size, ranging from pebbly very coarse to medium sand to a slightly silty medium to fine sand.

The uppermost unit is a fairly thin silty sandy gravel and occurs only in the northwestern portion of the 200-East Area.

Hydrology. The unconfined aquifer beneath the Hanford Site is contained within the Ringold Formation and the overlying Hanford formation. The unconfined aquifer is affected by disposal of wastewater to surface and subsurface disposal sites. The depth to groundwater ranges from 180 to 310 ft on the 200-Area Plateau. The bottom of the unconfined aquifer is the uppermost basalt surface or, in some areas, the clays of the lower Ringold Formation. The thickness of the unconfined aquifer in the 200 Areas ranges from less than 50 ft to 200 ft. Beneath the unconfined aquifer is a confined aquifer system consisting of sedimentary interbeds or interflow zones that occur between dense basalt flows or flow units.

The sources of natural recharge to the unconfined aquifer are rainfall from areas of high relief to the west of the Hanford Site and two ephemeral streams, Cold Creek and Dry Creek. From the areas of recharge, the groundwater flows downgradient and discharges into the Columbia River. This general flow pattern is modified by basalt outcrops and subcrops in the 200 Areas and by artificial recharge.

The unconfined aquifer beneath the 200 Areas receives artificial recharge from liquid disposal areas. Cooling water disposed to ponds has formed groundwater mounds beneath two former and one continuing high-volume disposal sites: U Pond in the 200-West Area, B Pond east of the 200-East Area, and Gable Mountain Pond north of the 200-East Area. The water table rose approximately 65 ft under U Pond and 30 ft under B Pond compared with pre-Hanford conditions (Newcomb et al. 1972). However, two of the ponds have been eliminated and, with no further recharge from them, the water levels will decline over the coming years. U Pond was deactivated in 1984 and Gable Mountain Pond was decommissioned and backfilled in 1987. The volume of B Pond increased after the elimination of Gable Mountain Pond.

The dry nature (i.e., climate, waste form, depth to water, etc.) of the low level burial ground (LLBG) and the limited natural surface recharge available from precipitation minimize the probability of leachate formation and migration from these facilities.

Additional characterization and enhanced groundwater monitoring of the 200 Area are currently being conducted pursuant to requirements established under the Resources Conservation and Recovery Act (RCRA). When complete, this work will supply additional information on the 200 Area.

4.2.10 300 Area

Three geologic formations have been identified during drilling operations conducted in the 300 Area. These are, in ascending order, the Columbia River Basalts, the Ringold Formation, and the glaciofluvial sediments (Pasco Gravels and Touchet Beds) known informally as the Hanford formation.

The Columbia River Basalts are of Miocene age and form the bedrock beneath the Hanford Site, which includes the 300 Area. The middle- to upper-Miocene subgroup is called the Yakima Basalt and is about 10.5 to 16.5 my old (Myers et al. 1979). These flood basalts were extruded from fissure systems in the eastern and southern portions of the Columbia Plateau (Swanson et al. 1979). The individual flows comprising the formation range in thickness from about 3 to 48 m (10 to 150 ft), and are sometimes separated by sedimentary interbeds. The basalts were originally flat-lying, broad synclinal structures, but have been locally warped and folded, producing anticlinal ridges and valleys. The Pasco syncline is a broad depression of basalt flows in the southeastern part of the Pasco Basin (Myers et al. 1979). The 300 Area is located in this syncline. At the 300 Area, the top of the basalts is at a depth of about 60 m (200 ft) below land surface.

The Ringold Formation overlies the basalts. This formation is of Pliocene age [approximately 3 to 5 my old (Gustafson 1978)] and with the exception of a weakly consolidated conglomerate member (Middle Ringold), consists mainly of layered silts, clays, and fine sands deposited in a lacustrine environment. The conglomerate member is considered to have been deposited in a high-energy, fluvial environment. Distinctive lithologic zones within this formation in the southeastern portion of the Hanford Site include: 1) blue and green silts and clays of the lower Ringold, and 2) a conglomerate consisting of well-rounded pebbles and cobbles, with medium-to-fine sand filling the interstitial spaces (Newcomb et al. 1972). Geologic logs of wells indicate that in the 300 Area the Ringold Formation consists of a series of sandy silt and clay layers but typically contains more than one permeable conglomerate or sand unit. Some of the silt layers are aerially continuous over much of the 300 Area. The Ringold Formation in this area is characteristically about 37 m (121 ft) thick.

Overlying the Ringold Formation are the glaciofluvial sediments, which are coarse clastic deposits laid down by the ancestral Columbia River when it was swollen by glacial meltwater (Newcomb et al. 1972). Drilling logs for wells in the 300 Area show this formation to consist of unconsolidated gravels and sands with some boulders and cobbles. A few of the drilling logs indicate a small amount of intermixed silt. Based on information from existing wells, the contact between the Ringold Formation and the glaciofluvial sediments in the 300 Area varies from about 14 to 18 m (46 to 60 ft) below the land surface and is distinguished by a change from sandy cobble and gravels to somewhat lighter colored, finer gravels with layers of silt.

Eolian (wind-transported and wind-deposited) material overlies the glaciofluvial sediments and consists of unsaturated silt and fine- to medium-grained sand. These deposits vary from 0.3 to 4 m (1 to 13 ft) in thickness with a range of 0.6 to 1.8 m (2 to 6 ft) being most typical. The geologic contact between the eolian deposits and the underlying glaciofluvial sediments is quite distinct.

Both unconfined and confined aquifers are present beneath the 300 Area. The uppermost aquifer is unconfined; underlying aquifers are contained in the basalts and are generally confined.

The aquifers in the basalts consist primarily of permeable zones at the contacts between basalt flows. The permeable zones, or interflow zones, are fractured vesicular basalt that occur at the upper and/or lower surfaces of the individual basalt flows and are the primary conduits for groundwater. Sand or gravel interbeds may also be present in the interflow zones and serve as conduits for groundwater.

In the 300 Area, the water table (the upper surface of the unconfined aquifer) is in the glaciofluvial sediments. The lower part of the unconfined aquifer, which may be partially confined, is in the Ringold Formation. The water table is at a depth of about 12 m (40 ft) below the land surface and the top of the Ringold Formation at depth of 14 to 20 m (46 to 66 ft).

Natural recharge of the unconfined aquifer beneath the Hanford Site occurs at the northwest margin of the Pasco Basin; most of the artificial recharge occurs at the 200 Areas near the center of the Site. Groundwater flows from these recharge areas toward the 300 Area in a general southeasterly direction. In the southeast corner of the Hanford Site, groundwater recharge is mainly from the Yakima River. The 300 Area is located approximately at the point where these two groundwater sources meet. As a result, groundwater enters the 300 Area from the northwest, west, and southwest (Lindberg and Bond 1979). Water level measurements collected on a monthly basis from a network of wells located in and around the 300 Area have been used to produce a series of recent (1985-1986) water table maps.

Near the 300 Area Process Trenches, groundwater generally flows toward the river to the southeast and east. Exact direction of groundwater flow at any given time is determined by both natural and human influences. The primary natural influence is the level of water in the Columbia River. Lindberg and Bond (1979) verified that when the river stage rises during spring run-off, bank storage occurs and causes a reversed water table gradient in the 300 Area. During these times groundwater tends to flow in a more southeasterly direction in a direction roughly subparallel to the river. When the river level drops, the natural gradient is restored and groundwater flows more easterly, in a direction nearly perpendicular to the river.

Characterization of the 300 Area Process Trenches and groundwater monitoring for RCRA compliance is currently underway. Field data collection is complete, and additional data will be available in the near future.

4.3 ECOLOGY

The Hanford Site is a relatively large, undisturbed area [1450 km^2 (~560 mi^2)] of shrub-steppe that contains numerous plant and animal species adapted to the region's semiarid environment. The site consists of mostly undeveloped land with widely spaced clusters of industrial buildings located along the western shoreline of the Columbia River and at several locations in the interior of the site. The industrial buildings are interconnected by roads, railroads, and electrical transmission lines. The major facilities and activities occupy about 6% of the total available land area, and their impact on the surrounding ecosystems is minimal. Most of the Hanford Site has not experienced tillage or livestock grazing since the early 1940s. The Columbia River flows through the Hanford Site, and although the river flow is not directly impeded by artificial dams within the Hanford Site, the historical daily and seasonal water fluctuations have been changed by dams upstream and downstream of the site (Rickard and Watson 1985). The Columbia River and other water bodies on the Hanford Site provide habitat for aquatic organisms. These habitats are discussed in detail in Subsection 4.3.2. The Columbia River is also accessible for public recreational use and commercial navigation. Other descriptions of the ecology of the Hanford Site can be found in ERDA (1975), Rogers and Rickard (1977), Jamison (1982), and Watson et al. (1984), among others.

4.3.1 Terrestrial Ecology

Vegetation

The Hanford Site, located in southeastern Washington, has been botanically characterized as a shrub-steppe (Daubenmire 1970). Because of the aridity, the productivity of both plants and animals is relatively low compared with other natural communities. In the early 1800s, the dominant plant in the area was big sagebrush with an understory of perennial bunchgrasses, especially Sandberg's bluegrass and bluebunch wheatgrass. With the advent of settlement that brought livestock grazing and crop raising, the natural vegetation mosaic was opened to a persistent invasion by alien annuals, especially cheatgrass. Today cheatgrass is the dominant plant on fields that were cultivated 40 years ago. Cheatgrass is also well established on rangelands at elevations less than 244 m (800 ft) (Rickard and Rogers 1983). Wildfires in the area are common; the most recent extensive fire in 1984 significantly altered the shrub component of the vegetation. The dryland areas of the Hanford Site were treeless in the years before land settlement; however, for several decades before 1943, trees were planted and irrigated on most of the farms to provide windbreaks and shade. When the farms were abandoned in 1943, some of the trees died but others have persisted, presumably because their roots are deep enough to contact groundwater. Today these trees serve as nesting platforms for several species of birds, including hawks, owls, ravens, magpies, and great blue herons, and as night roosts for wintering bald eagles (Rickard and Watson 1985). Today, the vegetation mosaic of the Hanford Site consists of eight major kinds of plant communities:

- sagebrush/bluebunch wheatgrass
- sagebrush/cheatgrass or sagebrush/Sandberg's bluegrass
- sagebrush-bitterbrush/cheatgrass
- greasewood/cheatgrass-saltgrass
- winterfat/Sandberg's bluegrass
- thyme buckwheat/Sandberg's bluegrass

- cheatgrass-tumble mustard
- willow

The distribution of the dominant plant communities is shown in Figure 4.3-1, and a list of common plants is given in Table 4.3-1.

The release of water used as industrial process coolant streams at the Hanford Site facilities created several semipermanent artificial ponds that did not exist before these industrial releases commenced. Over the years, stands of cattails, reeds, and trees, especially willow, cottonwood, and Russian olive, have developed around the ponds. These ponds are ephemeral and will disappear if the industrial release of water is terminated; in fact, many of these have been discontinued and no longer exist.

More than 240 species of plants have been identified on the Hanford Site (ERDA 1975). The dominant plants on the 200-Area Plateau are big sagebrush, rabbitbrush, cheatgrass, and Sandberg's bluegrass, with cheatgrass providing half of the total plant cover. Cottonwood, willows, cattails, and bullrushes grow along the banks of ponds and ditches. Near the 100 Areas, cheatgrass and riparian plants are the most prevalent, and big sagebrush, bitterbrush, rabbitbrush, cheatgrass, and Sandberg's bluegrass are common in the 300 and 400 Areas. More than 100 species of plants have been identified in the 200 Area Plateau (ERDA 1975). Cheatgrass and Russian thistle, which are annuals introduced to the United States from Eurasia in the late 1800s, invade areas where the ground surface has been disturbed. A food web centered on cheatgrass is shown in Figure 4.3-2 (modified from Watson et al. 1984). The main links leading to man would be through mule deer and chukar partridge. Certain desert plants have roots that grow to depths approaching 10 m (33 ft) (Napier 1982); however, root penetration to these depths has not been demonstrated for plants in the 200 Areas. Rabbitbrush roots have been found at a depth of 2.4 m (8 ft) near the 200 Areas (Klepper et al. 1979). Mosses and lichens appear abundantly on the soil surface; lichens commonly grow on the shrub stems.

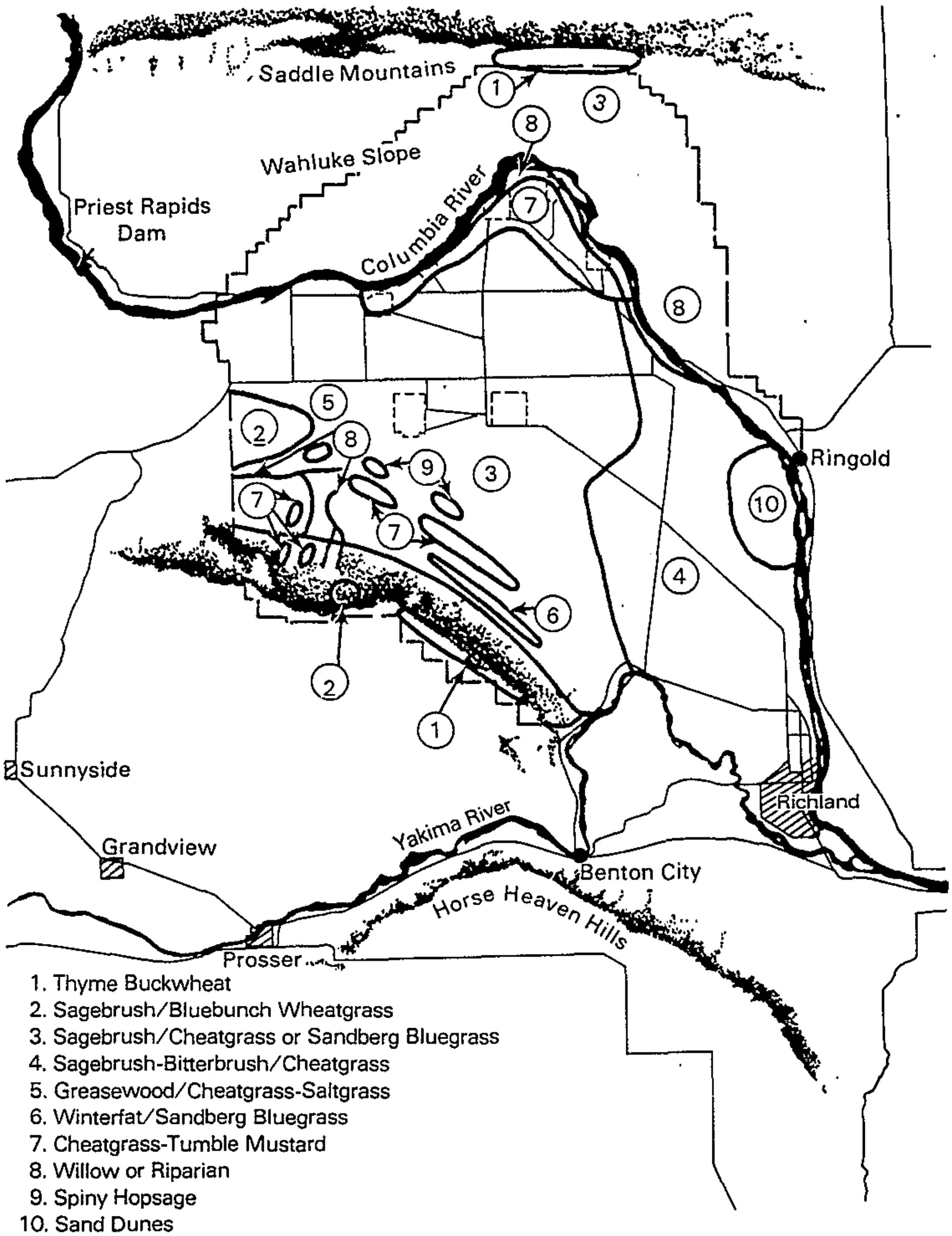


FIGURE 4.3-1. Distribution of Vegetation Types on the Hanford Site

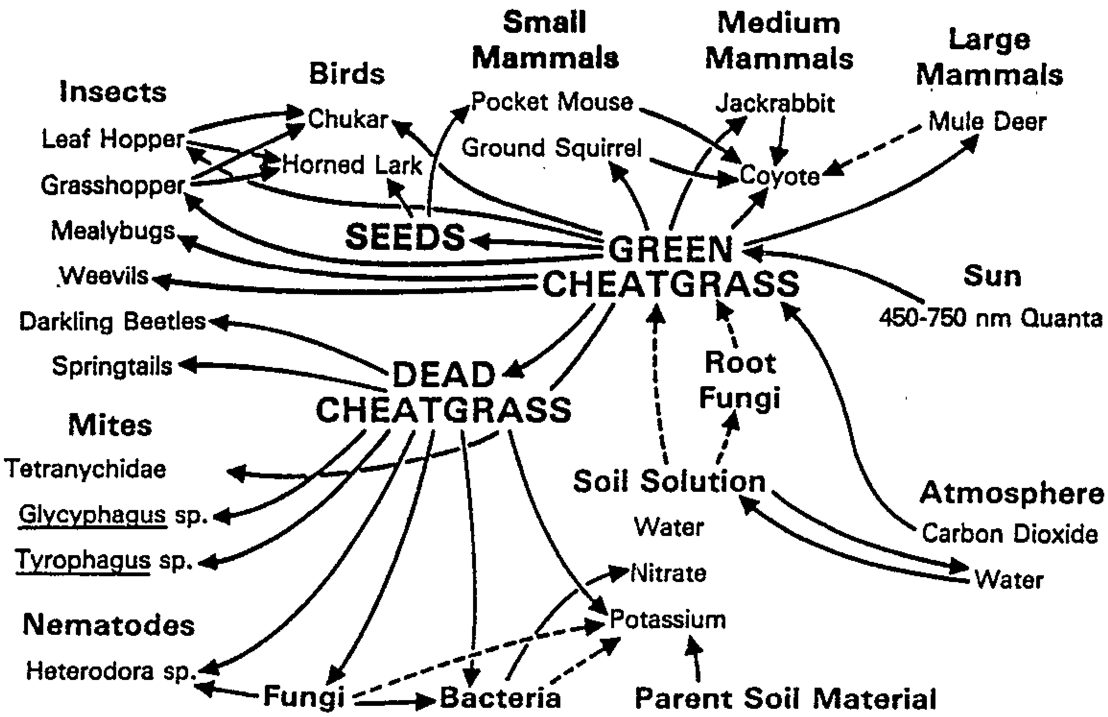
TABLE 4.3-1. Common Vascular Plants on the Hanford Site

Shrubs	Scientific Name
Big sagebrush	*Artemisia tridentata*
Spiny hopsage	*Grayia (Atriplex) spinosa*
Grey rabbitbrush	*Chrysothamnus nauseous*
Green rabbitbrush	*Chrysothamnus viscidiflorus*
Bitterbrush	*Purshia tridentata*
Snowy buckwheat	*Eriogonum niveum*
Perennial Grasses	
Sandberg's bluegrass	*Poa sandbergii (secunda)*
Needle and thread	*Stipa comata*
Indian ricegrass	*Oryzopsis hymenoides*
Crested wheatgrass	*Agropyron desertorum (cristatum)*[a]
Thick-spike wheatgrass	*Agropyron dasystachyum*
Sand dropseed	*Sporobolus cryptandrus*
Perennial Forbs	
Turpentine cymopterus	*Cymopterus terebinthinus*
Comandra	*Comandra umbellata*
Scurf pea	*Psoralea lanciniata*
Pale evening primrose	*Oenothera pallida*
Cluster lily	*Brodiaea douglasii*
Yellow bell	*Frittillaria pudica*
Sandwort	*Arenaria franklinii*
Long-leaved phlox	*Phlox longifolia*
Thelypody	*Thelypodium lanciniatum*
Balsamroot	*Balsamorhiza careyana*
Cusick's sandflower	*Helianthus cusickii*
Desert mallow	*Sphaeralcea munroana*
Beard's tongue	*Penstemon acuminatus*
Sand dock	*Rumex venosus*
Yarrow	*Achillea millefolium*
Gray cryptantha	*Cryptantha leucopheea*
Milkvetch	*Astragalus speirocarpus*
Annual Forbs	
Jim Hill (tumble) mustard	*Sisymbrium altissimum*[a]
Tansy mustard	*Descurainia pinnata*
Spring draba	*Draba verna*[a]
Microsteris	*Microsteris gracillis*
Matted cryptantha	*Cryptantha circumscissa*
Hawk's beard	*Crepis atrabarba*
Hoary aster	*Aster canescens*
Western wall flower	*Erysimum asperum*
Jagged chickweed	*Holosteum umbellatum*[a]
Polemonium	*Polemonium micranthum*
Blazing star	*Mentzelia albicaulis*
Phacelia	*Phacelia linearis*

TABLE 4.3-1. (contd)

Annual Forbs (contd)	Scientific Name
Yellow salsify	*Tragopogon dubius*[a]
Russian thistle (tumbleweed)	*Salsoa kali*[a]
Plantago	*Plantago purshii*
Purple mustard	*Chorispora tenella*[a]
False yarrow	*Chaenactis douglasii*
Cryptantha	*Cryptantha pterocarya*
Willow-herb	*Epilobium paniculatum*
Plectritis	*Plectritis macrocera*
Ragweed	*Ambrosia acanthicarpa*
Prickly lettus	*Lactuca serriola*[a]
Filaree (Crane's bill)	*Erodium cicutarium*[a]
Annual Grasses	
Cheatgrass	*Bromus tectorum*[a]
Six-weeks fescue	*Festuca octoflora*
Pacific fescue	*Festuca pacifica*
Trees and Shrubs	
Black cottonwood	*Populus trichocarpa*
Sand bar willow	*Salix exigua*
Peachleaf willow	*Salix amygdaloides*
Willow	*Salix* spp.
Mulberry	*Morus* sp.[a]
Dogbane	*Apocynum* sp.
Herbs	
Reed canary grass	*Phalaris arundinacea*
Cattail	*Typha latifolia*
Reeds	*Scirpus* spp.
Tickseed	*Coreopsis atkinsonia*
Golden aster	*Chrysopsis oregana*
Gumweed	*Grindelia* sp.
Goldenrod	*Solidago occidentalis*
Absinthe	*Artemisia absinthium*
Horsetail	*Equisetum arvense*
Gaillardia	*Gaillardia aristata*
Lupine	*Lupinus* spp.
Smartweed	*Polygonum amphibium*
Sedge	*Carex* spp.
Wiregrass	*Eleocharis* spp.
Speedwell	*Veronica anagallis-aquatica*
Wild onion	*Allium* spp.
Russian knapweed	*Centurea repens*[a]
Persistent sepal yellow cress	*Rorippa columbiae*
Watercress	*Rorippa nasturtium-aquatica*
Duckweed	*Lemna* spp.

(a) Exotic.



<u>FIGURE 4.3-2</u>. Food Web Centered on Cheatgrass (arrows indicate direction of energy and mass transfer)

The important desert shrubs, big sagebrush and bitterbrush, are widely spaced and usually provide less than 20% canopy cover. The important understory plants are grasses, especially cheatgrass, Sandberg's bluegrass, Indian ricegrass, June grass, and needle-and-thread grass.

As compared to other semiarid regions in North America, primary productivity is relatively low and the number of vascular plant species is also low. This is attributed to the low annual precipitation [16 cm (~6 in.)] the low water-holding capacity of the rooting substrate (sand), and the droughty summers and occasionally very cold winters.

Sagebrush and bitterbrush are easily killed by summer burning, but the grasses and other herbs are relatively resistant and usually recover in the first growing season after burning. Burning usually opens the community to wind erosion. The severity of erosion depends on the severity and areal extent of the burn. Hot burns incinerate entire shrubs and damage grasscrowns. Less intensive burns leave dead stems standing, and recovery of herbs is prompt. The most recent and extensive wildfire occurred in the summer of 1984.

Bitterbrush shrubs provide browse for a resident herd of wild mule deer. Bitterbrush shrubs are slow to recolonize burned areas because invasion is by seeds. Bitterbrush does not sprout even when burn damage is relatively light.

Certain passerine birds rely on sagebrush and/or bitterbrush for nesting (i.e., sage sparrow, sage thrasher, and loggerhead shrike). These birds are not expected to nest in places devoid of shrubs. Jackrabbits also appear to avoid burned areas without shrubs. Birds that nest on the ground in areas without shrubs are longbilled curlews, horned larks, Western meadowlarks, and burrowing owls.

Insects

More than 300 species of terrestrial and aquatic insects have been found on the Hanford Site (ERDA 1975). Grasshoppers and darkling beetles are among the more conspicuous groups and, along with other species, are important in the food web of the local birds and mammals. Most species of darkling beetles occur throughout the spring to fall period, although some species are present only during 2 or 3 months in the fall (Rogers and Rickard 1977). Grasshoppers are evident during the late spring to fall. Both groups are subject to wide annual variations in abundance. A food web centered on grasshoppers is shown in Figure 4.3-3 (Watson et al. 1984). The link leading to the Swainson's hawk is of concern in this case because it is a federal candidate for threatened and endangered designation.

An estimation of the relative densities of various insect taxa is given in Table 4.3-2.

Reptiles and Amphibians

Approximately 16 species (Table 4.3-3) of amphibians and reptiles have been observed at the Hanford Site (ERDA 1975). The occurrence of these species is infrequent when compared with similar fauna of the southwestern United States. The side-blotched lizard is the most abundant reptile and can be found throughout the Hanford Site. Short-horned and sagebrush lizards are

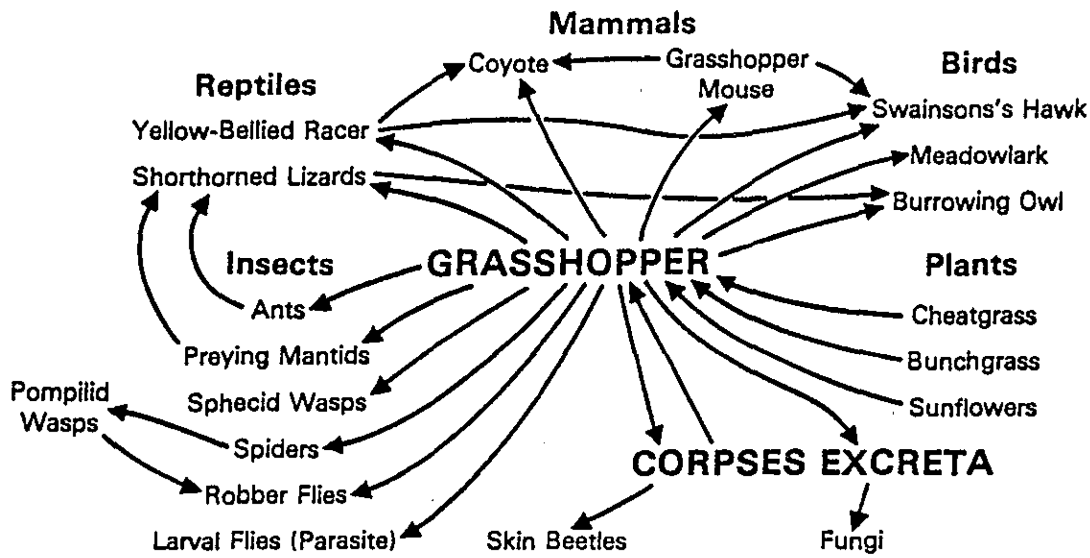


FIGURE 4.3-3. Food Web Centered on Grasshoppers (arrows indicate direction of energy and mass transfer)

TABLE 4.3-2. Relative Abundance (%) of Insect Taxa Collected from Sagebrush, Rabbitbrush, and Hopsage (Rogers 1979)

Taxa	Sagebrush	Rabbitbrush	Hopsage
Hemiptera	44.6	11.7	6.4
Homoptera	33.0	31.2	6.1
Orthoptera	7.3	24.0	21.8
Araneida	6.5	20.7	21.3
Hymenoptera	4.2	2.9	5.8
Coleoptera	1.7	1.9	27.4
Lepidoptera	1.2	6.1	5.3
Diptera	1.1	1.2	5.3
Neuroptera	0.3	0.3	0.3
Other	0.1	0.1	0.3

TABLE 4.3-3. Amphibians and Reptiles Occurring on the Hanford Site

Common Name	Scientific Name
Amphibians	
Great Basin spadefoot toad	*Spea intermontanus*
Western toad	*Bufo boreas*
Woodhouse toad	*Bufo woodhouseii*
Pacific treefrog	*Hyla regilla*
Bullfrog	*Rana catesbeiana*
Reptiles	
Sagebrush lizard	*Sceloporus graciosus*
Side-blotched lizard	*Uta stansburiana*
Short-horned lizard	*Phrynosoma douglassii*
Striped whipsnake	*Masticophis taeniatus*
Western yellow-bellied racer	*Coluber constrictor*
Gopher snake	*Pituophis melanoleucus*
Western terrestrial garter snake	*Thamnophis elegans*
Common garter snake	*Thamnophis sirtalis*
Desert night snake	*Hyspiglena torquata*
Pacific rattlesnake	*Crotalus viridis*

also common in selected habitats. The most common snakes are the gopher snake, the yellow-bellied racer, and the Pacific rattlesnake, which are found throughout the Hanford Site. Striped whipsnakes and desert night snakes are rarely found, but some sightings have been recorded for the site. Toads and frogs are found near the permanent water bodies and along the Columbia River.

Birds

More than 125 species of birds have been identified from the Hanford Site (Rogers and Rickard 1977). The horned lark and western meadowlark are the most abundant nesting birds in the shrub-steppe. Some of the more common birds present on the Hanford Site are listed in Table 4.3-4.

The Hanford Site supports populations of chukar partridge, gray partridge, and sage grouse. The greatest concentrations of these birds are in

TABLE 4.3-4. Partial List of the Common Birds Found on the Hanford Site

Common Name	Scientific Name
Great blue heron	*Ardea herodias*
Canada goose	*Branta canadensis moffitti*
Mallard	*Anas platyrhynchos*
Red-tailed hawk	*Buteo jamaicensis*
Swainson's hawk	*Buteo swainsoni*
Rough-legged hawk	*Buteo lagopus*
Sage grouse	*Centrocereus urophasianus*
California quail	*Callipepla californicus*
Ring-necked pheasant	*Phasianus colchicus*
Chukar partridge	*Alectoris chukar*
Gray (Hungarian) partridge	*Perdix perdix*
American coot	*Fulica americana*
California gull	*Larus californicus*
Ring-billed gull	*Larus delawarensis*
Mourning dove	*Zenaidura macroura*
Horned lark	*Eremophila alpestris*
Black-billed magpie	*Pica pica*
Western meadowlark	*Sturnella neglecta*
Sage sparrow	*Amphispiza belli*

the Rattlesnake Hills. The sage grouse population is very small and appears to be confined entirely to the slopes of the Rattlesnake Hills. The mourning dove nests throughout the Hanford Site. Small isolated populations of Chinese ring-necked pheasants and California quail live along the Columbia River and near the spring-streams in the Rattlesnake Hills. A food web centered on chukar partridge is shown in Figure 4.3-4 (Watson et al. 1984). Chukar partridge are hunted and eaten by humans.

Wastewater ponds at the Hanford Site are important habitats for songbirds, shore birds, ducks, and geese (Fitzner and Price 1973; Fitzner and Rickard 1975; Fitzner and Schreckhise 1979). The American coot is an abundant aquatic nesting bird on these sites. The ponds are used by a variety

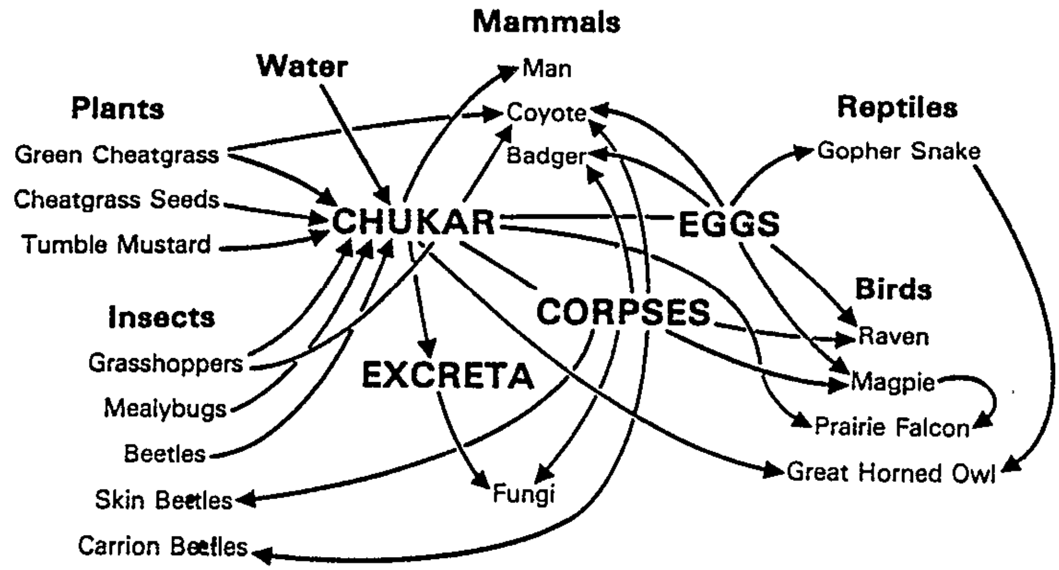


FIGURE 4.3-4. Food Web Centered on Chukar Partridge (arrows indicate direction of energy and mass transfer)

of waterfowl during fall migration. The most important resident waterfowl is the Canada goose, whose nesting habitat is confined to the islands of the free-flowing reach of the Columbia River (Hanson and Eberhardt 1971). Forester's tern, ring-billed gulls, and California gulls also nest on the islands. The Columbia River also serves as a major resting area for migrant waterfowl. The greatest concentrations of ducks and geese occur in the autumn months, and waterfowl hunting is a popular recreational activity where it is permitted on certain islands. The Hanford Site is located in the Pacific Flyway; in addition, a major sandhill crane flyway passes over the site.

Hawks and owls use the Hanford Site as a refuge, especially during nesting (Fitzner et al. 1980).

Mammals

Approximately 30 species of mammals have been identified on the Hanford Site (Table 4.3-5). Most are small and nocturnal. Of this group, the Great Basin pocket mouse is the most abundant; other species include the deer mouse, Townsend's ground squirrel, Northern pocket gopher, Western harvest mouse, house mouse, Norway rat, sagebrush vole, grasshopper mouse, vagrant shrew,

TABLE 4.3-5. List of Mammals Occurring on the Hanford Site

Common Name	Scientific Name
Merriam's shrew	*Sorex merriami*
Vagrant shrew	*Sorex vagrans*
Little brown bat	*Myotis lucifugus*
Silver-haired bat	*Lasionycteris noctivagans*
California brown bat	*Myotis californicus*
Yuma brown bat	*Myotis yumanensis*
Big brown bat	*Eptesicus fuscus*
Pallid bat	*Antrozous pallidus*
Hoary bat	*Lasiurus cinereus*
Raccoon	*Procyon lotor*
Mink	*Mustela vison*
Long-tailed weasel	*Mustela frenata*
Short-tailed weasel	*Mustela ermineu*
Badger	*Taxidea taxis*
Striped skunk	*Mephitis mephitis*
Coyote	*Canis latrans*
Bobcat	*Lynx rufus*
Least chipmunk	*Eutamias minimus*
Yellow-bellied marmot	*Marmota flaviventris*
Townsend's ground squirrel	*Spermophilus townsendii*
Northern pocket gopher	*Thomomys talpoides*
Great Basin pocket mouse	*Perognathus parvus*
Beaver	*Castor canadensis*
Western harvest mouse	*Reithrodontomys megalotis*
Deer mouse	*Peromyscus maniculatus*
Northern grasshopper mouse	*Onychomys leucogaster*
Montane meadow mouse	*Microtus montanus*
Bushy-tailed woodrat	*Neotoma cinerea*
Sagebrush vole	*Lagurus curtatus*
Muskrat	*Ondatra zibethicus*
House mouse	*Mus musculus*
Norway rat	*Rattus norvegicus*
Porcupine	*Erethizon dorsatum*
Black-tailed jackrabbit	*Lepus californicus*
White-tailed jackrabbit	*Lepus townsendi*
Nuttall's cottontail rabbit	*Sylvilagus nuttallii*
Mule deer	*Odocoileus hemionus*
White-tailed deer	*Odocoileus virginianus*
Elk	*Cervus elaphus*

least chipmunk, and Merriam's shrew. Nuttall's cottontail rabbits are widely distributed throughout the dryland habitats of the Hanford Site, and the black-tailed jackrabbit is found scattered throughout the lower elevations.

Muskrats and porcupines have been observed along the shorelines of streams, ponds, and ditches, and beavers are residents of the sloughs along the Columbia River. Raccoons, skunks, bobcats, mink, and badgers are also present on the site. The coyote is the principal mammalian predator on the site.

Larger mammals found include the mule deer and elk. The herd of elk is centered almost entirely on the Arid Lands Ecology (ALE) reserve (see Figure 4.3-7, p. 4.97), a part of the Hanford Site established as an environmental research study area in 1968. The mule deer are found mostly along the Columbia River and in the Rattlesnake Hills, although they move throughout the site.

Seven species of bats are also present on the Hanford Site.

4.3.2 Aquatic Ecology

There are two types of natural aquatic habitats on the Hanford Site; one is the Columbia River, which flows along the northern and eastern edges of the Hanford Site, and the other is provided by the small spring-streams and seeps located mainly on the ALE site in the Rattlesnake Hills. Several artificial water bodies, both ponds and ditches, have been formed as a result of wastewater disposal practices associated with the operation of the reactors and separation facilities. These are temporary and will vanish with cessation of activities, but while present, they form established aquatic ecosystems (except West Pond) complete with representative flora and fauna (Emery and McShane 1980). West Pond is created by a rise in the water table in the 200 Areas and is not fed by surface flow; thus, it is alkaline and has a much restricted complement of biota.

The Columbia River

The Columbia River is the dominant aquatic ecosystem on the Hanford Site and supports a large and diverse community of plankton, benthic invertebrates, fish, and other communities. It is the fifth largest river in North America and has a total length of about 2000 km (~1240 mi) from its origin in British Columbia to its mouth at the Pacific Ocean. The Columbia has been dammed both upstream and downstream from the Hanford Site, and the reach flowing through the area is the last free-flowing, but regulated, reach of the Columbia River in the United States. Plankton populations in the Hanford Reach are influenced by communities that develop in the reservoirs of upstream dams, particularly Priest Rapids Reservoir, and manipulation of water levels below by dam operations in downstream reservoirs. Phytoplankton and zooplankton populations at Hanford are largely transient, flowing from one reservoir to another. There is generally insufficient time for characteristic endemic groups of phytoplankton and zooplankton to develop in the Hanford Reach. No tributaries enter the Columbia during its passage through the Hanford Site.

The Columbia River is a very complex ecosystem because of its size, the number of manmade alterations, the diversity of the biota, and the size and diversity of its drainage basin. Streams in general, especially smaller ones, usually depend on organic matter from outside sources (terrestrial plant debris) to provide energy for the ecosystem. Large rivers, particularly the Columbia River with its series of large reservoirs, contain significant populations of primary energy producers (algae, plants) that contribute to the basic energy requirements of the biota. Phytoplankton (free-floating algae) and periphyton (sessile algae) are abundant in the Columbia River and provide food for herbivores such as immature insects, which in turn are consumed by carnivorous species. Figure 4.3-5 is a simplified diagram of the food web relationships in selected Columbia River biota and represents probable major energy pathways. Public Law 100-605 authorizes a study of the Hanford Reach of the Columbia River. The purpose of this study is to identify and evaluate the outstanding features of the Hanford Reach of the Columbia River and immediate environment, and to examine alternatives for their preservation.

Phytoplankton. Phytoplankton species identified from the Hanford Reach include diatoms, golden or yellow-brown algae, green algae, blue-green algae, red algae, and dinoflagellates. Diatoms are the dominant algae in the Columbia River phytoplankton, usually representing more than 90% of the populations. The main genera include *Asterionella*, *Cyclotella*, *Fragilaria*, *Melosira*, *Stephanodiscus*, and *Synedra* (Neitzel et al. 1982a). These are typical of those forms found in lakes and ponds and originate in the upstream

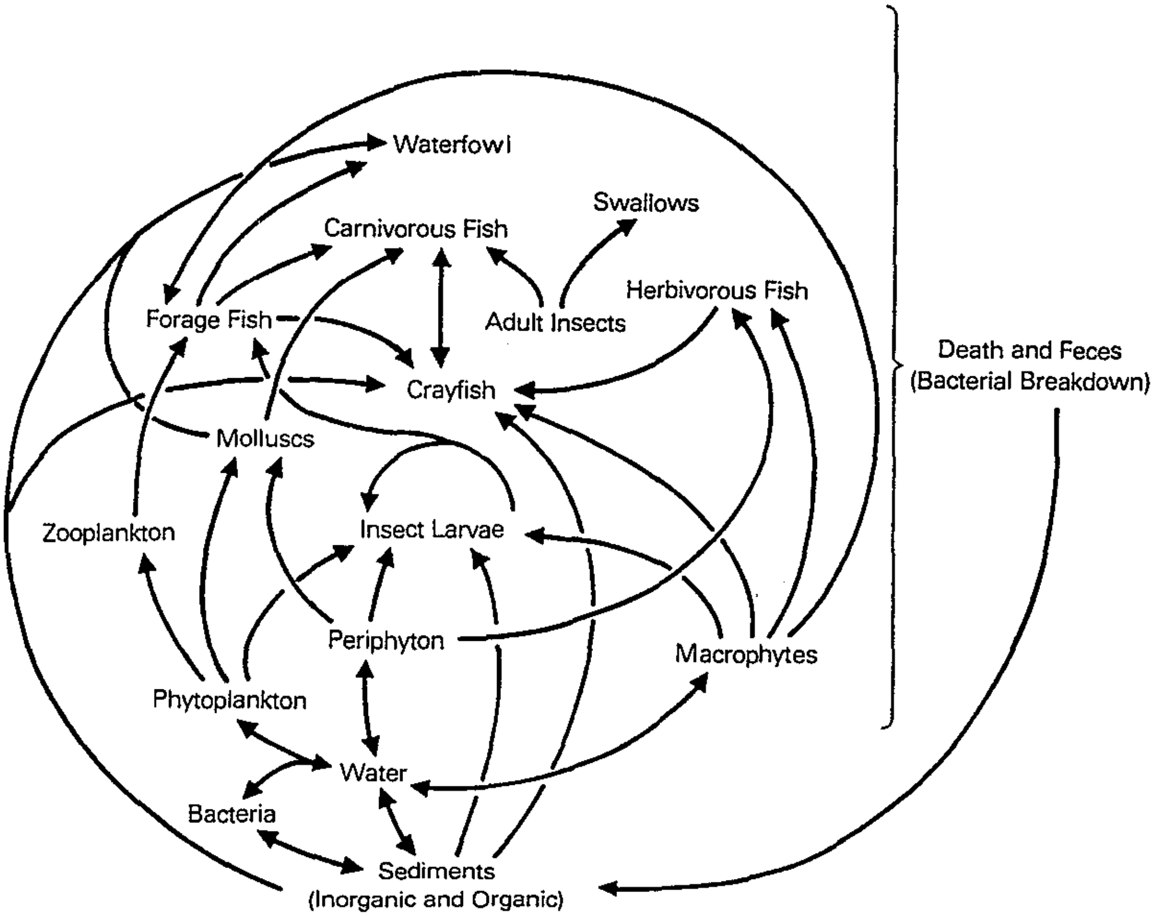


FIGURE 4.3-5. Food Web in the Columbia River

reservoirs. A number of algae found as free-floating species in the Hanford Reach of the Columbia are actually derived from the periphyton; they are detached and suspended by the current and frequent fluctuations of the water level. The peak concentration of phytoplankton is observed in April and May, with a secondary peak in late summer/early autumn (Cushing 1967a). The spring pulse in phytoplankton density is probably related to increasing light and water temperature rather than to availability of nutrients because phosphate and nitrate nutrient concentrations are never limiting. Minimum numbers are present in December and January. Green algae (Chlorophyta) and blue-green algae (Cyanophyta) occur in the phytoplankton community during warmer months, but in substantially fewer numbers than the diatoms. Diversity indices, carbon uptake, and chlorophyll a concentrations for the phytoplankton at various times and places can be found in Wolf et al. (1976), Beak Consultants Inc. (1980), and Neitzel et al. (1982a).

Periphyton. Communities of periphytic species ("benthic microflora") develop on suitable solid substrates wherever there is sufficient light for photosynthesis. Peaks of production occur in spring and late summer (Cushing 1967b). Dominant genera are the diatoms *Achnanthes*, *Asterionella*, *Cocconeis*, *Fragillaria*, *Gomphonema*, *Melosira*, *Nitzchia*, *Stephanodiscus*, and *Synedra* (Page and Neitzel 1978; Page et al. 1979; Beak Consultants Inc. 1980; Neitzel et al. 1982a).

Macrophytes. Macrophytes are sparse in the Columbia River because of the strong currents, rocky bottom, and frequently fluctuating water levels. Rushes (*Juncus* spp.) and sedges (*Carex* spp.) occur along the shorelines of the slack-water areas such as the White Bluffs Slough, below 100-H Area, the slough area downstream of the 100-F Area, and the Hanford Slough. Macrophytes are also present along gently sloping shorelines that are subject to flooding during the spring freshet and daily fluctuating river levels (below Coyote Rapids and 100-D Area). Commonly found plants include *Lemna*, *Potamogeton*, *Elodea*, and *Myriophyllum*. Where they exist, macrophytes have considerable ecological value. They provide food and shelter for juvenile fish and spawning areas for some species of warm-water game fish.

Zooplankton. The zooplankton populations in the Hanford Reach of the Columbia are generally sparse. In the open water regions, crustacean zooplankters are dominant. Dominant genera are *Bosmina*, *Diaptomus*, and *Cyclops*. Densities are lowest in winter and highest in the summer. Summer peaks are dominated by *Bosmina* and range up to 4500 organisms/m^3. Winter densities are generally less than 50 organisms/m^3. *Diaptomus* and *Cyclops* dominate in winter and spring, respectively (Neitzel et al. 1982b).

Benthic Organisms. Benthic organisms are found either attached to or closely associated with the substrate. All major freshwater benthic taxa are represented in the Columbia River. Insect larvae such as caddisflies (Trichoptera), midge flies (Chironomidae), and black flies (Simuliidae) are dominant. Dominant caddisfly species are *Hydropsyche cockerelli*, *Cheumatopsyche campyla*, and *C. enonis*. Other benthic organisms include limpets, snails, sponges, and crayfish. Peak larval insect densities are found in late fall and winter, and the major emergence is in spring and summer (Wolf 1976). Stomach contents of fish collected in the Hanford Reach from June 1973 through March 1980 revealed that benthic invertebrates are important food items for nearly all juvenile and adult fish. There is a close relationship between food organisms in the stomach contents and those in the benthic and invertebrate drift communities.

Fish. Gray and Dauble (1977) list 43 species of fish in the Hanford Reach of the Columbia River. The brown bullhead (*Ictalurus nebulosus*) has been collected since 1977, bringing the total number of fish species identified in the Hanford Reach to 44 (Table 4.3-6). Of these species, the chinook salmon, sockeye salmon, coho salmon, and steelhead trout use the river as a migration route to and from upstream spawning areas and are of the greatest economic importance. Both the fall chinook salmon and steelhead trout also spawn in the Hanford Reach. Since 1962, the Hanford Reach spawning population has represented about 15% to 20% of the total fall chinook escapement to the river. The destruction of other mainstream Columbia spawning grounds by dams has increased the relative importance of the Hanford Reach spawning (Watson 1970, 1973).

The estimates of the annual average Hanford Reach steelhead spawning population estimates for the years 1962 to 1971 were about 10,000 fish. The estimated annual sport catch for the period 1963 to 1968 in the reach of the river from Ringold to the mouth of the Snake River was approximately 2,700 fish (Watson 1973).

The shad, another anadromous species, may also spawn in the Hanford Reach. The upstream range of the shad has been increasing since 1956 when fewer than 10 adult shad ascended McNary Dam. Since then, the number ascending Priest Rapids Dam, immediately upstream from Hanford, has risen to many thousands each year and the young-of-the-year have been collected in the Hanford Reach. The shad is not dependent on specific current and bottom

TABLE 4.3-6. Fish Species in the Hanford Reach of the Columbia River

Common Name	Scientific Name
White sturgeon	Acipenser transmontanus
Bridgelip sucker	Catostomus columbianus
Largescale sucker	Catostomus macrocheilus
Mountain sucker	Catostomus platyrhynchus
Pumpkinseed	Lepomis gibbosus
Bluegill	Lepomis macrochirus
Smallmouth bass	Micropterus dolomieui
Largemouth bass	Micropterus salmoides
White crappie	Pomoxis annularis
Black crappie	Pomoxis nigromaculatus
American shad	Alosa sapidissima
Prickley sculpin	Cottus asper
Mottled sculpin	Cottus bairdi
Piute sculpin	Cottus beldingi
Reticulate sculpin	Cottus perplexus
Torrent sculpin	Cottus rotheus
Chiselmouth	Acrocheilus alutaceus
Carp	Cyprinus carpio
Peamouth	Mylocheilus caurinus
Northern squawfish	Ptychocheilus oregonensis
Longnose dace	Rhinichthys cataractae
Leopard dace	Rhinichthys falcatus
Speckled dace	Rhinichthys osculus
Redside shiner	Richardsonius balteatus
Tench	Tinca tinca
Burbot	Lota lota
Threespine stickleback	Gasterosteus aculeatus
Black bullhead	Ictalurus melas
Yellow bullhead	Ictalurus natalis
Brown bullhead	Ictalurus nebulosus
Channel catfish	Ictalurus punctatus
Yellow perch	Perca flavescens
Walleye	Stizostedion vitreum vitreum
Sand roller	Percopsis transmontana
Pacific lamprey	Entosphenus tridentatus
River lamprey	Lampetra ayresi
Lake whitefish	Coregonus clupeaformis
Coho salmon	Oncorhynchus kisutch
Sockeye salmon	Oncorhynchus nerka
Chinook salmon	Oncorhynchus tshawytscha
Mountain whitefish	Prosopium williamsoni
Cutthroat trout	Oncorhynchus clarki
Rainbow trout (steelhead)	Oncorhynchus mykiss
Dolly Varden	Salvelinus malma

conditions required by the salmonids for spawning and has apparently found favorable conditions for reproduction throughout much of the Columbia River and the Snake River.

Other fish of importance to sport fishermen are the whitefish, sturgeon, smallmouth bass, crappie, catfish, walleye, and perch. Large populations of rough fish including carp, shiners, suckers, and squawfish are also present.

Spring Streams

The small spring streams, such as Rattlesnake and Snively springs, contain diverse biotic communities and are extremely productive (Cushing and Wolf 1984). Dense blooms of watercress occur, which are not lost until one of the major flash floods occurs. The aquatic insect production is fairly high as compared to mountain streams (Gaines 1987). The macrobenthic biota varies from site to site and is related to the proximity of colonizing insects and other factors.

Rattlesnake Springs on the western side of the Hanford Reservation forms a small surface stream that flows for about 2.5 km (1.6 mi) before disappearing into the ground as a result of seepage and evapotranspiration. Base flow of this stream is about 0.01 m^3/sec (0.4 cfs) (Cushing and Wolf 1982). Water temperature ranges from 2° to 22°C (36° to 72°F). Mean annual total alkalinities (as $CaCO_3$, nitrate nitrogen, phosphate phosphorous, and total dissolved solids) are 127, 0.3, 0.18, and 217 mg/L, respectively (Cushing and Wolf 1982; Cushing et al. 1980). The sodium content of the spring water is about 7 ppm (Brown 1970). It is of ecological importance because it provides a source of water to terrestrial animals in an otherwise arid part of the reservation. Snively Springs, located farther west and at a higher elevation than Rattlesnake Springs, apparently does not contribute to the flow of Rattlesnake Springs (Brown 1970), but probably flows to the west and off the Hanford Site. The major rooted aquatic plant, which in places may cover the entire width of the stream, is watercress (*Nasturtium officinale* = *Rorippa nasturtium-aquaticum*). Isolated patches of bulrush (*Scirpus* sp.), spike rush (*Eleocharis* sp.), and cattail (*Typha latifolia*) occupy less than 5% of the stream bed.

9 0 1 0 3 1 2 3 7

Primary productivity at Rattlesnake Springs was greatest during the spring and coincident with the maximum periphyton standing crop. Net primary productivity averaged 0.9 $g \cdot cm^{-2} \cdot d^{-1}$ during 1969-1970; the spring maximum was 2.2 $g \cdot cm^{-2} \cdot d^{-1}$. Seasonal productivity and respiration rates are within the ranges reported for arid region streams. Although Rattlesnake Springs was a net exporter of organic matter during much of the growing season, it is subject to flash floods and severe scouring and denuding of the stream bed during winter and early spring, making it an importer of organic materials on an annual basis (Cushing and Wolf 1984).

An inventory of the many springs occurring on the Rattlesnake Hills has been published by Schwab et al. (1979). Limited physical and chemical data are included for each site.

Temporary Water Bodies

The temporary wastewater ponds and ditches have been in place for as long as two decades, although many have been eliminated. Rickard et al. (1981) discussed the ecology of Gable Mountain Pond, one of the former major lentic sites. Emery and McShane (1980) presented the ecological characteristics of all the temporary sites. The ponds develop luxuriant riparian communities and become quite attractive to autumn and spring migrating birds; several species nest in the vicinity of the ponds. Some of these ponds and ditches are shown in Figure 4.3-6.

4.3.3 Threatened and Endangered Species

Threatened and endangered plants and animals, as listed by the federal government (DOI 1986) and Washington State (Washington National Heritage Program 1990) are shown in Table 4.3-7. There are no plants or mammals on the federal list of Endangered and Threatened Wildlife and Plants (DOI 1986; 50 CFR 17.11, 17.12) that are known to occur on the Hanford Site. There are, however, several species of both plants and animals that are under consideration for formal listing by the federal government and Washington State.

Plants

Two species of plants are included in the Washington State listing. Columbia milk-vetch (Astragalus columbianus Barneby) is listed as threatened,

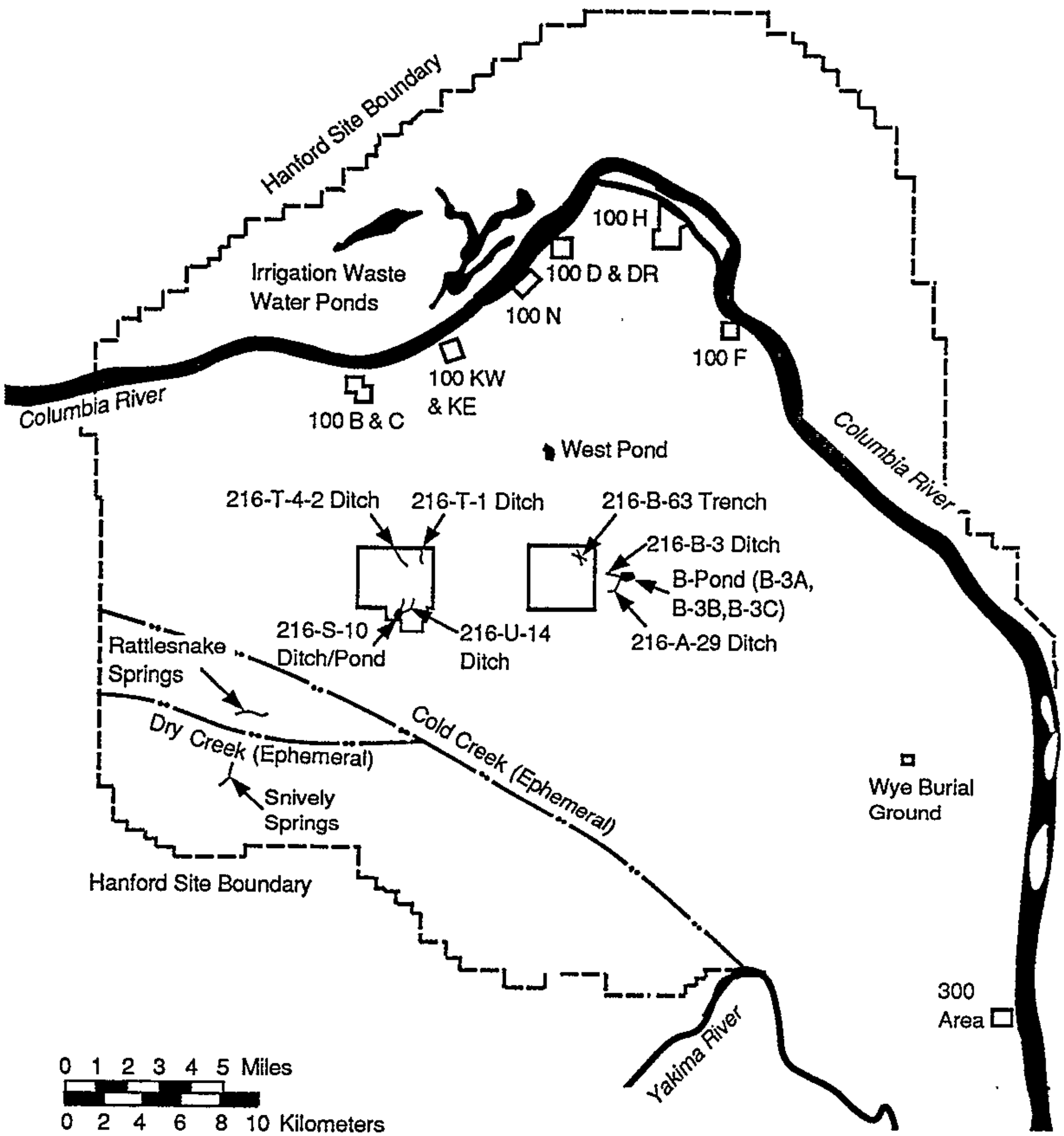


FIGURE 4.3-6. Temporary Ponds and Ditches, Including Ephemeral Streams, on the Hanford Site

TABLE 4.3-7. Threatened (T) and Endangered (E) Species

Common Name	Scientific Name	Federal	State
Plants			
Columbia milk-vetch	Astragalus columbianus		T
Yellowcress	Rorippa columbiae		E
Birds			
Aleutian Canada goose	Branta canadensis leucopareia	E	E
Peregrine falcon	Falco peregrinus	E	E
Bald eagle	Haliaeetus leucocephalus	T	T
White pelican	Pelecanus erythrorhychos		E
Sandhill crane	Grus canadensis		E
Ferruginous hawk	Buteo regalis		T

and yellowcress (Rorippa columbiae Suksd.) is designated as endangered. Columbia milk-vetch occurs on dry land benches along the Columbia River in the vicinity of Priest Rapids Dam, Midway, and Vernita. Yellowcress occurs in the wetted zone of the water's edge along the Columbia River.

Birds

The federal government lists the Aleutian Canada goose (Branta canadensis leucopareia) and the peregrine falcon (Falco peregrinus) as endangered and the bald eagle (Haliaeetus leucocephalus) as threatened. The state of Washington lists, in addition to the peregrine falcon, Aleutian Canada goose, and bald eagle, the white pelican (Pelecanus erythrorhynchos) and sandhill crane (Grus canadensis) as endangered, and the ferruginous hawk (Buteo regalis) as threatened. The peregrine falcon is a casual migrant to the Hanford Site and does not nest here. The bald eagle is a regular winter resident and forages on dead salmon and waterfowl along the Columbia River; it does not nest on the Hanford Site. Increased use of power poles for nesting sites by the ferruginous hawk on the Hanford Site has been noted. Washington State Bald Eagle Protection Rules were issued in 1986 (WAC 232-12-292). These rules require DOE to prepare a management plan to mitigate eagle disturbance. The Endangered Species Act of 1973 will also require that Section 7 consultation be undertaken when any action is taken that may jeopardize the existence, or destroy, or adversely modify habitat of the bald eagle or other endangered species.

Table 4.3-8 lists the designated candidate species that are under consideration for possible addition to the threatened or endangered list.

4.3.4 Wildlife Refuges

Several national and state wildlife refuges are located on or adjacent to the Hanford Site. These refuges are shown in Figure 4.3-7.

4.3.5 100 Areas

For most purposes, the ecological characterization of the Hanford Site can be used. Some unique characteristics of the 100 Areas follow.

Terrestrial Ecology

Cheatgrass is prevalent because of the extensive perturbation of the soils in these areas. The characteristic communities found are cheatgrass-tumble mustard, sagebrush/cheatgrass or Sandberg's bluegrass, sagegrass-bitterbrush/cheatgrass, and willow-riparian vegetation near the Columbia River shoreline.

TABLE 4.3-8. Candidate Species

Common Name	Scientific Name	Federal	State
Molluscs			
Great Columbia River limpet	*Fisherola* (= *Lanx*) *nuttalli*		X
Giant Columbia spire snail	*Fluminicola* (= *Lithoglyphus*) *columbiana*		X
Birds			
Common loon	*Gavia immer*		X
Swainson's hawk	*Buteo swainsoni*	X	
Ferruginous hawk	*Buteo regalis*	X	
Long-billed curlew	*Numenius americanus*	X	

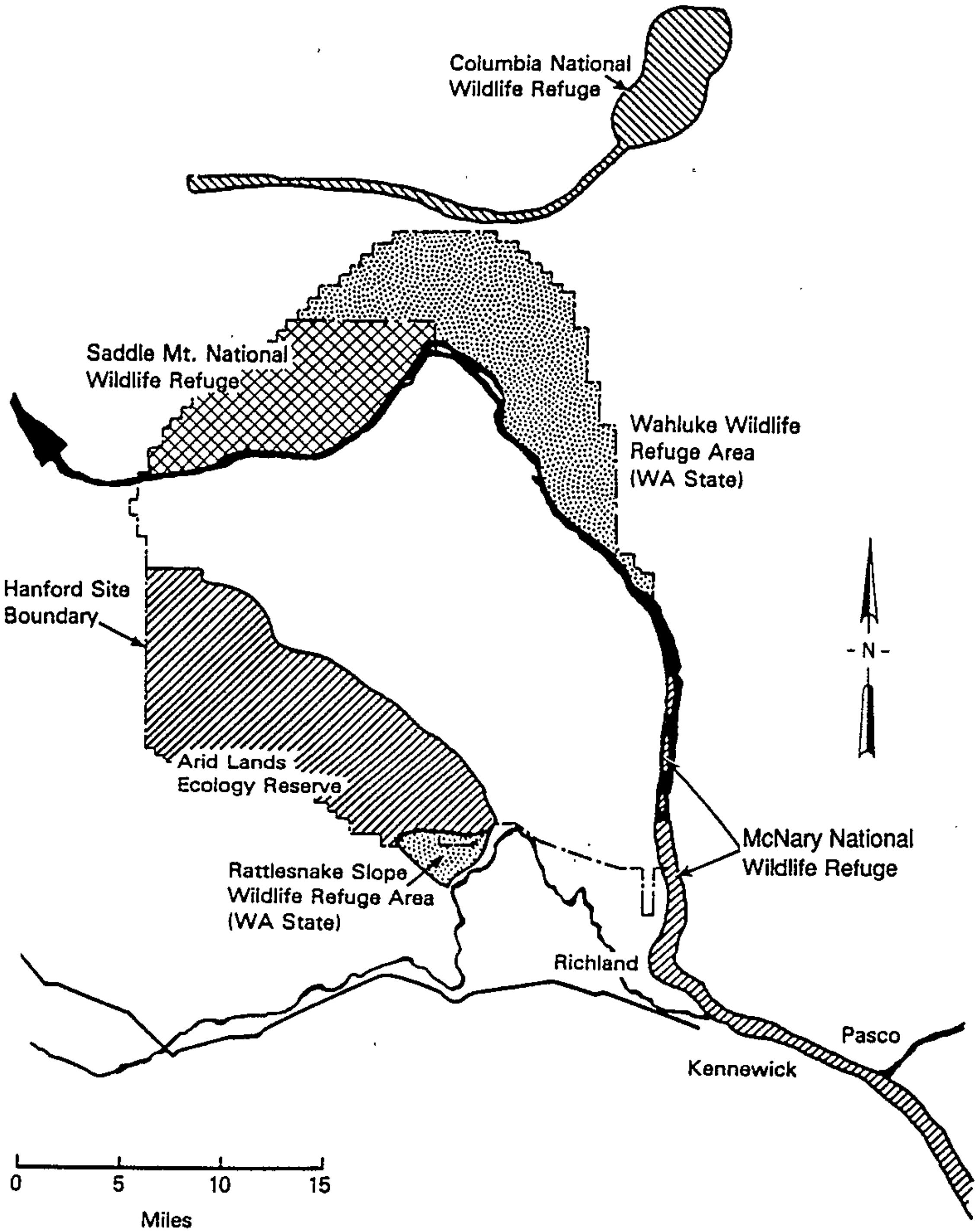


FIGURE 4.3-7. National and State Wildlife Refuges in the Vicinity of the Hanford Site

The insects, reptiles, amphibians, birds, and mammals found in this area are the same ones common for the Hanford Site with the following exceptions. California quail and Chinese ring-necked pheasants are more likely to be found near the Columbia River, and several mammals, such as raccoons, beaver, and porcupines, are more likely to be present near water.

Aquatic Ecology

The major aquatic site related to the 100 Areas is, of course, the Columbia River, which flows past each of the reactor sites. The ecology of the Columbia River is presented in the Hanford Site section.

Threatened and Endangered Species

Two of the plants listed by the State of Washington occur in proximity to the Columbia River and could be found in the 100 Areas. They are the Columbia milk-vetch (*Astragalus columbianus* Barneby), listed as threatened, and yellowcress (*Rorippa columbiae* Suksd.) designated as endangered.

4.3.6 200 Areas

The description of the ecological characteristics of the Hanford Site can be used for most work pertaining to the 200 Areas. Unique features are described here.

Terrestrial Ecology

Most of the plant communities occurring on the Hanford Site can be found near the 200 Areas, or at least on the 200-Area Plateau. The sagebrush/cheatgrass or Sandberg's bluegrass community is perhaps the most common in the area.

The insects, birds, reptiles, amphibians, and mammals common to the Hanford Site can be found in this area.

Aquatic Ecology

The aquatic sites found in the 200 Areas are the temporary water bodies described under the general Hanford Site section and are those associated with waste disposal practices. No other unique sites occur in this area.

4.3.7 300 Area

There are no unique terrestrial or aquatic ecological characteristics to the 300 Area. It most closely resembles the 100 Areas because of the proximity of the Columbia River.

The ant populations of the Hanford 300 Area waste burial grounds were characterized by Fitzner et al. (1979). The species encountered were *Solenopsis molesta*, *Pogonomyrmex owyheei*, *Formica subpolita*, and *Formica manni*. The habits of each species are provided in Fitzner et al. (1979). Ants are of some concern in radioactive waste management because they can excavate soil to a depth of several meters. Buried waste can thus be transported from shallow waste burial sites to the surface.

4.4 HISTORICAL, ARCHAEOLOGICAL, AND CULTURAL RESOURCES

The Hanford Site is known to be rich in cultural resources. It contains numerous, well-preserved archaeological sites representing both the prehistoric and historical periods and is still thought of as a homeland by many Indian people (Chatters 1989).

4.4.1 Archaeological Resources

People have inhabited the Middle Columbia River region since the end of the glacial period. More than 10,000 years of prehistoric human activity in this largely arid environment have left extensive archaeological deposits along the river shores (Leonhardy and Rice 1970; Greengo 1982; Chatters 1989). Well-watered areas inland from the river also show evidence of concentrated human activity (Chatters 1982, 1989; Daugherty 1952; Greene 1975; Leonhardy and Rice 1970; Rice 1980). Graves are common in various settings, and spirit quest monuments are still to be found on high, rocky summits of the mountains and buttes (Rice 1968a). Throughout most of the region, hydroelectric development, agricultural activities, and domestic and industrial construction have destroyed or covered over the majority of these deposits. Amateur artifact collectors have had an immeasurable impact on what remains. By virtue of their inclusion in the Hanford Site, from which the public is restricted, archaeological deposits found in the Hanford Reach of the Columbia River and on adjacent plateaus and mountains have been spared some of the disturbances that have befallen other sites. The Hanford Site is thus a de facto reserve of archaeological information of the kind and quality that has been lost elsewhere in the region.

There are currently 160 prehistoric archaeological sites recorded in the files of the Washington State Office of Archaeology and Historic Preservation. Forty-seven of these sites are included on the National Register of Historic Places (National Register), two as single sites (45BN121, Hanford Island Site; 45GR137, Paris Site) and the remainder in seven archaeological districts (Table 4.4-1). In addition, a nomination has been prepared for one cultural district (Gable Mountain/Gable Butte), and renomination for two additional archaeological districts is pending (Wahluke, Coyote Rapids) (Table 4.4-2). One other area has been identified as a locality with extensive low-density scatters of artifacts and other cultural remains; this is the shifting dunes locality, which lies between the 400 and 100-F Areas. Archaeological sites include numerous villages of pithouse remains, various types of open campsites and cemeteries along the river banks (Rice 1968a, 1980), spirit quest

TABLE 4.4-1. Historic Properties on the Hanford Site Listed on the National Register of Historic Places and the Archaeological Sites Included in Them

Property	Sites
Wooded Island A.D.[a]	45BN107 through 45BN112, 45BN168
Savage Island A.D.	45BN116 through 45BN119, 45FR257 through 45FR262
Hanford Island Site	45BN121
Hanford North A.D.	45BN124 through 45BN133, 45BN134, 45BN178
Locke Island A.D.	45BN137 through 45BN140, 45BN176 45GR302 through 45GR305
Ryegrass A.D.	45BN149 through 45BN157
Paris Site	45GR137
Rattlesnake Springs A.D.	45BN170, 45BN171
Snively Canyon A.D.	45BN172, 45BN173

(a) A.D. indicates archaeological district (this table).

TABLE 4.4-2. Historic Properties on the Hanford Site Which Have Been Nominated to the National Register of Historic Places or for Which Nominations Have Been Prepared

Property Name[a,b]	Site(s) Included
Gable Mountain/Gable Butte A.D.[a]	45BN348 through 45BN352, 45BN354-363, 45BN402 through 45BN410
Wahluke A.D.[b]	45BN141 through 45BN147; 45GR306
Coyote Rapids A.D.[b]	45BN152; 45GR312 through 45GR314 105-B Building

(a) Nomination forms have been prepared. A.D., archeological district (this table).
(b) Nominated; rejected because of lack of documentation; renomination is pending.

monuments (rock cairns), hunting camps and game drive complexes in mountains and rocky bluffs (Rice 1968b), and small temporary camps near perennial sources of water located away from the river (Rice 1968b).

Most recorded sites were found during four archaeological reconnaissance projects conducted between 1926 and 1968 (Krieger 1928; Drucker 1948; Rice 1968a, 1968b). Systematic Archaeological Surveys conducted in the late 1970s and the 1980s are responsible for the remainder (Chatters 1989; Chatters et al. 1990; Cleveland et al. 1976; Rice 1981, 1987; Smith et al. 1977; Thoms et al. 1983). Little excavation has been conducted at any of the sites, and the Mid-Columbia Archaeological Society (MCAS) has done most of that work. They have conducted minor test excavations at several sites on the river banks and islands (Rice 1980) and a larger scale test at site 45BN157 (Den Beste and Den Beste 1976). The University of Idaho also excavated a portion of site 45BN179 (Rice 1980) and collaborated with the MCAS on its other work. Test excavations have been conducted at the Wahlula (45GR306), Vernita Bridge (45BN90), and Tsulim (45BN412) sites; results are pending. The majority of the archaeological survey and reconnaissance activity has concentrated on islands and on a strip of land less than 400 m wide on either side of the river (Rice 1980). During his reconnaissance of the Hanford Site in 1968, Rice (1968b) inspected portions of Gable Mountain, Gable Butte, Snively Canyon, Rattlesnake Mountain, and Rattlesnake Springs but gave little attention to other areas. Rice inspected additional portions of Gable Mountain and part of Gable Butte in the late 1980s (Rice 1987). Some reconnaissance of the Basalt Waste Isolation Project Reference Repository Location (RRL; Rice 1984), a proposed land exchange in T22N, R27 E, Section 33 (Rice 1981), and three narrow transportation and utility corridors (ERTEC 1982; Morgan 1981; Smith et al. 1977) was also conducted. A stratified random sample survey is being conducted by the Hanford Cultural Resources Laboratory in nonriverine areas of the site (Chatters et al. 1990). Cultural resource reviews are conducted when projects are proposed for areas that have not been previously reviewed.

4.4.2 Native American Cultural Resources

In prehistoric and early historic times, the Hanford Reach of the Columbia River was heavily populated by Indian people of various tribal affiliations. The Wanapum and the Chamnapum band of the Yakima tribe dwelled along the Columbia River from south of Richland upstream to Vantage (Relander 1956; Spier 1936). Some of their descendants still live nearby, and others have been incorporated into the Yakima and Umatilla reservations. Palus people, who lived on the lower Snake River, joined the Wanapum and Chamnapum to fish the Hanford Reach and some inhabited the river's east bank (Relander 1956; Trafzer and Scheuerman 1986). Walla Walla and Umatilla people also made periodic visits to the area to fish. These peoples retain traditional secular and religious ties to the region, and there are many, young and old alike, who have knowledge of the ceremonies and lifeways of their aboriginal culture. The Seven Drums religion, which has ancient roots and had its start on the Hanford Site, is still practiced by many people on the Yakima, Umatilla, Warm Springs, and Nez Perce reservations. Native plant and animal foods, some of which can be found on the Hanford Site, are used in the ceremonies performed by sect members. Certain landmarks, especially Rattlesnake Mountain, Gable Mountain, Gable Butte, Goose Egg Hill, and various sites along the Columbia River, are sacred to them. These people also consider the many cemeteries that are found along the river to be sacred.

4.4.3 Historic Resources

The first Euro-Americans who came into this region were Lewis and Clark, who traveled along the Columbia and Snake rivers during their 1803-1806 exploration of the Louisiana Territory. They were followed by fur trappers, who also passed through on their way to more productive lands up and down river and across the Columbia Basin. It was not until the 1860s that merchants set up stores, a freight depot, and the White Bluffs Ferry on the Hanford Reach. Chinese miners began to work the gravel bars for gold. Cattle ranches opened in the 1880s and farmers soon followed. Several small, thriving towns, including Hanford, White Bluffs, and Ringold, grew up along the riverbanks in the early twentieth century. Other ferries were established at Wahluke and Richmond. The towns and nearly all other structures were razed after the U.S. Government acquired the land for the Hanford Nuclear Reservation in the early 1940s (Chatters 1989; ERTEC 1981; Rice 1980).

Eleven historic archaeological sites and eleven other historic localities have been recorded in published literature. Localities include the Allard Pumping Plant at Coyote Rapids, the Hanford Irrigation Ditch, the Hanford townsite, Wahluke Ferry, the White Bluffs townsite, the Richmond Ferry, Arrowsmith townsite, a cabin at East White Bluffs ferry landing, the White Bluffs road, the old Hanford High School, and the Cobblestone Warehouse at Riverland (Rice 1980). Archaeological sites include the East White Bluffs townsite and associated ferry landings, and an assortment of trash scatters and dumps. This relative paucity of historic sites is more apparent than real, and is because the focus of archaeological surveys has been on prehistoric remains to the extent that only one survey (ERTEC 1982) recorded any historic Euro-American sites. ERTEC was also responsible for minor test excavations at some of the sites, including the Hanford townsite locality. In addition to the few recorded sites, there are numerous areas of gold mine tailings along the river bank, and the remains of homesteads, ranches, and abandoned Army installations are scattered over the entire Hanford Site.

More recent are the defense reactors and associated materials processing facilities that now dominate the site. The first reactors (100-B, 100-D, and 100-F) were constructed in 1943 as part of the Manhattan Project. Plutonium for the first atomic explosion and the bomb that destroyed Nagasaki to end World War II were produced in the 100-B Facility. Additional reactors and processing facilities were constructed after World War II, during the Cold War. All reactor containment buildings still stand, although many ancillary structures have been removed. The 100-B Reactor has been nominated to the National Register of Historic Places, and a review of other Manhattan Project facilities is pending.

4.4.4 100 Areas

Except for a portion of 100-N, the 100 Areas have not been surveyed for cultural resources. Much of the surface area within the 100 Areas has been disturbed by the industrial activities that have taken place over the last 40 years. However, the proximity of numerous archaeological sites indicates that significant cultural resources may exist in the unsurveyed areas.

- 100-B and 100-C Areas. The 100-B Reactor is listed as a National Mechanical Engineering Landmark and has been nominated to the National Register of Historic Places. Other cultural resources are rare in the vicinity of 100-B and 100-C Areas, at least based on the level of reconnaissance that has been done there. Only three sites can be identified from the literature (Rice 1968a, 1980). Site 45BN153 lies partially within the 100-B and 100-C Areas, and 45GR315 and the remains of the early twentieth-century town of Haven lie on the opposite bank of the Columbia River. Site 45GR315 appears to contain artifact deposits as old as 3500 to 2500 years and requires test excavation before an evaluation of significance can be made. Site 45BN153 is not significant (Chatters et al. 1990).

- 100-D and 100-DR Areas. These are located in a segment of the Columbia River considered to be poor in cultural resources, at least on the basis of reconnaissance-level surveys. Two known archaeological sites lie within 2 km (1.2 mi) of the areas, both on the left (opposite) bank of the river. Sites 45GR307 and 308 are open campsites of unknown age (Rice 1968a). Neither has been considered to be eligible for the National Register of Historic Places, but no record exists of a formal evaluation of the sites having been completed. The townsite of twentieth-century Wahluke, which was at the landing of a ferry of the same name, is also situated on the river's left bank. The midchannel island off the 100-D and 100-DR areas may be the one called Watklimpt by the Wanapum Indians (Relander 1956).

- 100-F Area. The 100-F Area is situated on a segment of the Columbia River that contains a multitude of cultural sites. According to Relander (1956), camps and villages of the Wanapum people extended from the Hanford townsite upstream to the White Bluffs townsite. Among those were the villages of Walwaltkh, Tohoke, and Tacht and the sites of Wyone and Y'yownow, which were fishing and fish processing locations, respectively. Tacht (meaning White Bluffs) was one of the principal sedentary villages of the Wanapum. There are nine prehistoric archaeological sites within 2 km (1.2 mi) of this area, including 45BN132, 45BN133, 45BN134, 45BN136, 45BN137, 45BN178, 45FR264, 45FR265, and 45FR266. They all are identified as open camps, except for 45BN134, which contains housepits. Site 45FR264 appears to contain artifact deposits extending back to at least 6000 years B.P. Site 45BN178 included in the Hanford North Archaeological District, which is listed on the National Register of Historic Places. One additional site, 45BN128, is a cemetery.

  The principal historic site in the vicinity is the East White Bluffs ferry landing and townsite (site 45FR314h), which has been considered for nomination to the National Register of Historic Places. It is located on the east bank of the Columbia River and is coterminous with 45FR266. The site was the upriver terminus of shipping during the early and mid-nineteenth century. It was at this point that supplies for the trappers, traders, and miners were off-loaded and commodities from the interior were transferred from pack trains and wagons to river boats. The first store and ferry of the mid-Columbia region were located there (ERTEC 1981). A log cabin, thought to have been a blacksmith shop in the mid-nineteenth century, still stands there. Test excavations were conducted at the cabin by the University of Idaho, and the structure has been recorded according to standards of the Historic American Buildings Survey (Rice 1976).

- 100-H Area. This area is situated in what is probably the most culturally rich area on the Hanford Site, and, since construction of the dams elsewhere in the Columbia River system, the most archaeologically rich area in the western Columbia Plateau. There are 10 recorded archaeological sites within 2 km (1.2 mi) of the area, including 45BN138 through 45BN141, and 45GR302 (a, b, and c) through 45GR305. These include two historic Wanapum cemeteries, six camps (one associated with a cemetery), and three housepit villages. The largest village, 45GR302a, contains more than 60 housepits and numerous storage caches. It appears to have been occupied from 2500 years ago to historic times (Rice 1968a). All these sites are included in the Locke Island Archaeological District, which is listed in the National Register of Historic Places. Locke Island itself was known to the Wanapum Indians as K'watch (Relander 1956). The historic village of Tacht, which was still used until establishment of the Hanford Site, is located 1 km (0.6 mi) south of the reactor facility. Several living members of the Wanapum, Palus, and Yakima tribes recall residing there.

  The only recognized historic site in the vicinity is the White Bluffs Townsite. This settlement was founded in the twentieth century. It has not been evaluated for eligibility to the National Register of Historic places.

- 100-K Area. Events took place at this locality that may be of great significance to Indian people in the interior Northwest. It was here, in the mid-nineteenth century, that Smohalla, Prophet of the Wanapum people, held the first washat, the dance ceremony that has become central to the Seven Drums or Dreamer religion (Relander 1956), a sect of the traditional Washane. As a result of Smohalla's personal abilities, the religion spread to many neighboring tribes, and is now practiced in some form by members of the Colville, Nez Perce, Umatilla, Warm Springs, and Yakima tribes. The site of this historic event was the right bank of the Columbia River at Moon, or Water Swirl Place, which we call Coyote Rapids. There is an archaeological site there, 45BN152, that is just north of the area perimeter. Three other sites, 45GR312, 45GR313, and 45GR314, are on the opposite bank of the river. Together these sites comprise the Coyote Rapids Archaeological District. This district was nominated to the National Register of Historic Places, but the nomination was rejected in 1976 because of insufficient information. Recent reinspection of 45BN152 produced a finding of nonsignificance (Chatters et al. 1990). Sites 45BN149, 45BN150, and 45BN151 (the Ryegrass Archaeological District) are located just downstream of the 100-K Area; 45BN151 is a known cemetery.

- 100-N Area. The 100-N Area is situated on an archaeologically rich segment of the Columbia River's shore. Within 2 km (1.2 mi) of the area perimeter are eight archaeological sites, including 45BN149, 45BN150, 45BN151, 45BN179, and 45BN180 on the south shore and 45GR309, 45GR310, and 45GR311 on the north shore. Four of these are either listed on or considered eligible for inclusion on the National Register of Historic Places. Sites 45BN149, 45BN150, and 45BN151, which include two pithouse villages and one cemetery, respectively, comprise the Ryegrass Archaeological District. Site 45BN179, once considered for nomination as the Hanford Generating Plant Site, has been found to be part of 45BN149, which is already listed on the National Register (Chatters et al. 1990).

In 1973, Rice (1980) conducted test excavations at 45BN179. During that excavation, which consisted of excavating two trenches and two smaller pits [32 m^2 (~3 ft^2)], Rice found evidence of habitation during four periods of prehistory. The earliest, undated occupation of the site occurred during the Vantage Phase of the local chronology (Swanson 1962; Nelson 1969), which dates to before 4500 B.P. (3000 B.C.). Small amounts of material, also undated, were attributable to the Frenchman Springs Phase [4500 to 2500 B.P. (3000 to 500 B.C.)]. Above that were dense artifact deposits and remains of pithouses dating after 1862 B.P. (88 A.D.), which Rice attributed to the Cayuse Phase [2000 B.P. (50 B.C.) to historic times]. Capping the sequence of deposits was debris left by Wanapum Indian people during their historic occupation of the site. No excavations have been conducted in other sites within the Ryegrass Archaeological District, so their scientific potential is unknown.

Extant knowledge about the archaeology of the 100-N Area is based largely on reconnaissance-level archaeological surveys (e.g., Rice 1968b; see also Rice 1980), which do not purport to produce complete inventories of the areas covered. Only the vicinity of the Hanford Generating Plant has been surveyed intensively for archaeological resources (Rice 1980). Consequently, as-yet-undiscovered archaeological properties might exist in the 100-N Area and its immediate vicinity.

Three areas near the 100-N Area are known to have been of some importance to the Wanapum. The knobs and kettles south and east of the area were called Moolimooli, which means Little Stacked Hills. Coyote Rapids, which is a short distance upstream, was called Moon, or Water Swirl Place. Gable Mountain (called Nookshai or Otter) and Gable Butte, which lie to the south of the river, are sacred mountains where youths would go on overnight vigils seeking guardian spirits (Relander 1956). No sites of religious importance are known to exist within the 100-N compound.

The most common evidence of historic activity now found near the 100-N Area is provided by gold mine tailings on river banks and archaeological sites where homesteads once stood. Few of these vestiges of the early years remain. The double-fenced compound of the 100-N Area has been cleared of cultural resource concerns.

4.4.5 200 Areas

An archaeological survey has been conducted of all undeveloped portions of the 200-East Area, and a 50% random sample has been conducted of undeveloped portions of the 200-West Area. No archaeological sites or areas of Native American interest were found in either area and none are known to exist within 2 km (1.2 mi) of their boundaries (Chatters and Cadoret 1990). The only historic site is the old White Bluffs freight road (see Rice 1984) that crosses diagonally through the 200-West Area. A determination of eligibility will be sought for this property on the basis of information obtained during recent archaeological surveys.

4.4.6 300 Area

Archaeological surveys of the 300 Area have been confined to a narrow strip along the riverbanks (Cleveland et al. 1976; Drucker 1948; Rice 1968a; Thoms 1983). The only exception was an inspection of the right-of-way for a proposed toll bridge just south of the area boundary (Morgan 1981). Four archaeological sites are located partially within the 300 Area: 45BN29, 45BN105, 45BN106, and 45BN62. Ten other sites within 2 km of the area perimeter include 45BN28, 45BN30, 45BN31, 45BN104, and 45BN163 located on the right bank of the Columbia River; 45FR42, 45FR164, and 45FR308 located on islands in the river; and 45FR20 and 45FR21 located on the left bank. None of the sites in Benton County is currently considered eligible for the National Register, but there is no record of any of these having been subjected to the formal evaluation process. Consequently there is no information on the ages of the sites and little on their prehistoric uses. Sites have, however, been characterized according to their surface characteristics. Three of the sites in Benton County are housepit villages, including 45BN105, which is reported to contain four or five housepits (Rice 1968a). The remaining Benton County sites are open camping/fishing stations (four) and shell middens (two). The sites in Franklin County are outside the Hanford Site boundaries. Remains of homesteads and irrigation facilities can be seen on the heavily disturbed riverbank in and adjacent to this area, but these have not been systematically investigated and none are recorded as historic archaeological sites. Most of the 300 Area has been disturbed by industrial activities.

One locality important to the historic Wanapum Indians is located near the 300 Area. Sekema, a favorite place for taking salmon that had already spawned, was located some 10 km (6 mi) north of Richland (Relander 1956), which would place it 2 to 3 km (1.2 to 1.8 mi) north of the 300-Area boundary. However, because Relander's descriptions of geographic locations are only approximate, it is possible that Sekema corresponds to any or all of the Benton County (BN) archaeological sites listed previously.

4.4.7 400 Area

Most of the 400 Area has been so disrupted by construction activities that archaeologists surveying the site in 1978 were able to find only 30 acres that were undisturbed (Rice et al. 1978). They found no cultural resources in that small area. No sites are located within 2 km of the 400 Area.

4.4.8 1100 Area

No cultural resources have been identified in or near the 1100 Area. However, the area has not been thoroughly surveyed, so any statement about the lack of cultural values would be premature. No mention is made by Relander (1956) of any location important to the Wanapum Indians.

4.4.9 3000 Area

Archaeological surveys of the 3000 Area have been confined to a narrow strip along the river's banks (Cleveland et al. 1976; Drucker 1948; Rice 1968a; Thoms 1983). Twelve sites are within 2 km of the area perimeter, including 45BN267 located inland; 45BN26; 45BN27, 45BN28, and 45BN104 located on the west bank; 45BN43, 45BN44, 45BN101, 45BN102, 45BN103, and 45BN192 located on an island; and 45FR308 located on the east bank. None of the above-listed Benton County sites has been determined eligible for the National Register. However, none of the individual sites has been evaluated. Thoms (1983) recommended that these sites and others in the Tri-Cities area should be incorporated into an archaeological district, but that nomination has not been made. Site types represented in Benton County include one housepit/occupation site, six open camp/fishing stations, three shell middens, and one possible butchering site.

No historic sites have been identified for this area, but it is possible that homesteads and remnants of the North Richland townsite might be found there.

4.5 SOCIOECONOMICS

Activity on the Hanford Site plays a dominant role in the socioeconomics of the Tri-Cities (Richland, Pasco, and Kennewick) and other parts of Benton and Franklin counties. The agricultural community also has a significant employment, Hanford's payroll impacts the Tri-Cities and state economy. These effects are further described in Section 4.5.2.[a]

From October 1987 through September 1988, DOE and its contractors purchased approximately $96 million of goods and services in Washington State. The most recent study shows that total DOE procurement is estimated to have supported approximately 800 jobs in Benton and Franklin counties; most of these jobs are in the wholesale and retail sector (Scott et al. 1987).

Washington Public Power Supply System. Although activity related to nuclear power construction ceased with the completion of the WNP-2 reactor in 1983, the Washington Public Power Supply System continues as a major employer in the Tri-Cities area. Headquarters personnel based in Richland oversee the operation of one generating facility and perform a variety of functions related to two mothballed nuclear plants and one standby generating facility. In 1989, the Washington Public Power Supply System headquarters employment was nearly 1600 workers. Washington Public Power Supply System activities generated roughly a $62 million payroll in the Tri-Cities during the year.

Agriculture. Agricultural activities in Benton and Franklin counties are responsible for nearly 11,500 jobs, or nearly one-sixth of total employment. According to the U.S. Department of Commerce's Regional Economic Information System, about 2200 people were classified as farm proprietors in 1988. Farm proprietors' income from this same source was estimated to be $74.3 million in the same year.

Crop and livestock production in the bicounty area generated about 4900 wage and salary jobs in 1988, as represented by the employees covered by unemployment insurance. The presence of seasonal farm workers makes the total number of farm workers higher. Apart from the difficulty of obtaining reliable information on the number of seasonal workers, however, there is the question of how much of these earnings are actually spent in the local area.

(a) Scott, M. J., and D. Belzer. 1990. "Projecting Employment in the Tri-Cities Economy." Unpublished Technical Appendix to Tri-Cities Economy Review and Outlook, March 1990 Update. Pacific Northwest Laboratory, Richland, Washington.

effect on the local economy. Any major changes in Hanford activity would potentially most affect the Tri-Cities and other areas of Benton and Franklin counties. Detailed analyses of the socioeconomics are found in Scott et al. (1987) and Watson et al. (1984).

4.5.1 Employment and Income

Three major sectors have been the principal driving forces of the economy in the Tri-Cities since the early 1970s: 1) the DOE and its contractors operating the Hanford Site; 2) the Washington Public Power Supply System in its construction and operation of nuclear power plants; and 3) the agricultural community, including a substantial food-processing component. With the exception of a minor amount of agricultural commodities sold to local area consumers, the goods and services produced by these sectors are exported outside the Tri-Cities. In addition to the direct employment and payrolls, these major sectors also support a sizable number of jobs in the local economy through their procurement of equipment, supplies, and business services.

In addition to these three major employment sectors, three other components can be readily identified as contributors to the economic base of the Tri-Cities economy. The first of these, loosely termed "other major employers," includes six such employers: 1) Advanced Nuclear Fuels in North Richland, 2) Sandvik Special Metals in Kennewick, 3) Boise-Cascade in Wallula, 4) Burlington Northern Railroad, 5) Iowa Beef Processors, and 6) Cascade Columbia Airlines. The second component is tourism. The Tri-Cities area has increased its convention business substantially in recent years, in addition to business generated by travel for recreation. The final component in the economic base relates to the local purchasing power generated not from current employees but from retired former employees. Government transfer payments in the form of pension benefits constitute a significant proportion of total spendable income in the local economy.

DOE Contractors (Hanford). Hanford continues to dominate the local employment picture with almost one-quarter of the total jobs in Benton and Franklin counties in 1989 (12,788 of 56,678). Beyond Hanford's direct

2400. In 1987, business travel associated with visitors on DOE business generated an estimated $15 million payroll and roughly 1900 jobs in the local economy.

Retirees. Although the Benton and Franklin counties have a relatively young population (approximately 58% under the age of 35 as compared with a national average of 54%), almost 15,000 people over the age of 65 resided in Benton and Franklin counties in 1989. In fact, the portion of the total population that is 65 years and older is currently increasing at a greater rate than is being experienced by Washington State (2.6% and 3.7%, respectively). This segment of the population supports the local economy on the basis of income received from government transfer payments and pensions, private pension benefits, and prior individual savings.

Although information on private pensions and savings is not available, data are available regarding the magnitude of government transfer payments. The Department of Commerce's Regional Economic Information System has estimated transfer payments by various programs at the county level. A summary of estimated major government pension benefits received by the residents of Benton and Franklin counties in 1986 is shown in Table 4.5-1. The total transfer payment income was about $176 million in 1989, which is calculated

TABLE 4.5-1. Government Retirement Payments in Benton and Franklin Counties, 1988 (millions of dollars)

	Benton County	Franklin County	Total
Social Security (including survivors and disability)	84.8	27.6	112.4
Railroad retirement	2.3	3.1	5.4
Federal civilian retirement	8.9	2.6	11.5
Veterans pension and military retirement	12.5	3.0	15.5
State and local employee retirement	18.9	4.7	23.6
	$127.4	$41.0	$168.4

For this analysis, we assumed that the impact of seasonal workers on the local economy is sufficiently small to be safely ignored.

The area's farms and ranches generate a sizable number of jobs in supporting activities, such as agricultural services (e.g., application of pesticides and fertilizers, irrigation system development, etc.) and sales of farm supplies and equipment. These activities, often called "agri-business," are estimated to employ 1200 people. This figure has been reduced from the estimate of 1350 jobs made in 1981 by the Washington State Employment Security Department. Based on a somewhat depressed farm sector in 1986, as compared to 1981, this figure was reduced to 1200. For lack of better information, this 1200 figure was held constant for the 1988 estimate.

Although formally classified as a manufacturing activity, food processing is a natural extension of the farm sector. More than 20 food processors in Benton and Franklin counties produce such goods as potato products, canned fruits and vegetables, wine, and animal feed. Seasonally adjusted full-time employment in this sector averaged nearly 3200 in 1988.[a]

Other Major Employers. In 1988, other major employers--Advanced Nuclear Fuels, Sandvik Special Metals, Iowa Beef Processors, Boise-Cascade, Burlington Northern Railroad--employed more than 4000 people in Benton and Franklin counties. Although Boise Cascade's Wallula mill lies outside both Benton and Franklin counties, most of its workforce resides in the Tri-Cities.

Tourism. In recent years, tourism activity has increased significantly in the Tri-Cities. According to the Tri-Cities Visitors and Convention Bureau, in 1989 nearly 700 conventions or tournaments were held in the Tri-Cities with about 59,900 visitors who spent an estimated $13.9 million. A study by the Washington State Department of Tourism estimated that overall tourism expenditures in the Tri-Cities were roughly $72.5 million in 1989 and that travel-generated employment in Benton and Franklin counties was about

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(a) Scott, M. J., and D. Belzer. 1990. "Projecting Employment in the Tri-Cities Economy." Unpublished Technical Appendix to Tri-Cities Economy Review and Outlook, March 1990 Update. Pacific Northwest Laboratories, Richland, Washington.

by extrapolating 1988 figures by the change in the Consumer Price Index between 1988 and 1989. About two-thirds of the Social Security payments go to retired workers; the remainder are for disability and other payments. The historical importance of government activity in the Tri-Cities area is reflected in the relative magnitude of the government employee pension benefits as compared to total payments.

The Washington State Office of Financial Management estimated that 14,656 people 65 years or older lived in Benton and Franklin counties in 1989. Dividing this number into the estimated total transfer payment figure yields estimated per capita transfer payments of $12,000. However, some of these payments are received by younger retirees. Including the population aged 60 to 64, the per capita payment is reduced to about $9,000, which may be a reasonable lower bound. Data for 1980 show that monthly social security benefits in Benton County were about 9% higher than the national average. In addition, the greater share of retirees receiving government employee pensions, as mentioned above, is also likely contributing to the higher per capita figure.

The preceding discussion may help to reveal that the purchasing power of senior citizens is an important component of the Tri-Cities economy just as for the entire nation. Taken as a whole, the estimated income of this component of the basic sector is roughly equivalent to the entire agricultural sector.

Secondary Sector. The secondary sector consists of all other workers in Benton and Franklin counties. Wholesale and retail trade dominated the secondary sector with about 11,600 wage and salary workers.[a] Various services (excluding business services, mainly DOE contractor employment) employ about 10,700 people, and local government employs approximately 7,700 workers (State of Washington, Employment Security 1989). The remaining

(a) To some degree, wholesale and retail trade also contains a "basic" component, because the Tri-Cities serve as a regional trade center for an area reaching northward into Grant County and southward to Oregon. The extent of this basic activity is not known, but it results in an overstatement of the size of the secondary sector relative to the basic sector.

workers in the secondary sector are in transportation, communication, utilities, finance, real estate, and construction.

4.5.2 Hanford and the Local and State Economy

In 1989, Hanford employment accounted directly for 23% of total nonagricultural employment in Benton and Franklin counties and 0.7% of all nonagricultural state-wide jobs. In 1988, Hanford employed more Washingtonians than the entire primary aluminum industry and almost as many as the pulp and paper industry. Hanford accounted for more than two-thirds of Washington employment in chemicals and allied products, or about 3% of all Washington manufacturing jobs. Hanford Site operations directly account for an estimated 33% of the dollars earned in Benton and Franklin Counties in 1988 and 0.8% of all dollars earned in Washington State industries.

Previous studies reveal that each Hanford job supports about 1.2 additional jobs in the local service sector of Benton and Franklin Counties (about 2.2 total jobs) and about 1.5 additional jobs in the state's service sector (about 2.5 total jobs) (Scott et al. 1987). Similarly, each dollar of Hanford income supports about 2.1 dollars of total local incomes and about 2.4 dollars of total statewide incomes. Based on these multipliers in Benton and Franklin Counties, Hanford directly or indirectly accounts for more than 40% of all jobs.

Based on November 1, 1986, payroll records, 92% of the direct employment and payroll of Hanford go to residents of the Benton and Franklin counties. Nearly 80% of the employment and payroll go to residents who reside in one of the Tri-Cities. More than 45% of the payroll and employment go to Richland residents, 27.7% to Kennewick residents, and 9.5% to Pasco residents. West Richland, Benton City, Prosser, and other areas in Benton and Franklin counties account for 11.5% of total employment and payroll.

Hanford and contractors spent nearly $154 million, or 47.5% of total procurements of $324 million, initially through Washington firms in 1986. About 18% of Hanford orders were filled by Tri-Cities firms. In many cases, these procurements filled by Tri-Cities firms only result in retail and wholesale markups; however, a significant portion of all Hanford orders, $6.6 million, are placed directly to Washington manufacturers.

Contractors spent $22 million on electricity and other utilities in 1986, ordered nearly $19 million in business services, and spent $73 million on Washington retail and wholesalers. Finally, DOE and its contractors provided about $16 million (mainly in grants) to local governments and others for a variety of public purposes.

Hanford contractors paid a total of $10.9 million in FY 1988 in state taxes on operations and purchases. Estimates show that Hanford employees paid $27.0 million in state sales, use, and other taxes and fees in FY 1988. In addition, Hanford paid $0.9 million to local government in Benton, Franklin, and Yakima counties in local taxes and fees (Scott et al. 1989).

4.5.3 Demography

Estimates by Washington State's Office of Financial Management, dated April 1990, place the population totals of Benton and Franklin counties at 110,000 and 34,600, respectively. These estimates compare with similar 1980 census data in which Benton County had 109,444 residents and Franklin County's population totaled 35,025. The year 1982 represents the period with the highest population: an estimated 111,700 residents in Benton County and 36,200 residents in Franklin County.

Within each county, the 1990 estimates distribute the Tri-Cities population as follows: Richland, 30,250; Kennewick, 37,910; and Pasco, 17,820. The populations of Benton City, Prosser, and West Richland totaled 9,615 in 1990. The unincorporated population of Benton County was 32,225. In Franklin County, incorporated areas other than Pasco have a total population of 2,444. The unincorporated population of Franklin County was 14,336.

The 1989 estimates of racial categories by the Bureau of the Census indicate that Asians represent a lower proportion in Benton and Franklin counties while whites represent a higher proportion of the racial distribution than those in the state of Washington. Countywide, Benton and Franklin counties exhibit varying racial distributions as indicated by the calculations in Table 4.5-2.

TABLE 4.5-2. 1989 Population Estimates by Bureau of the Census Racial Categories and for Spanish Origin

	Total	White	Black	Indian	Asian	Other Race[a]	Spanish Origin[b]
Washington State	4,660,000	4,154,593	131,570	71,453	165,220	137,864	174,583
		89%	3%	2%	4%	3%	
Benton and Franklin Counties	138,300	128,894	2,182	950	1,811	4,463	8,776
		93%[c]	2%	0.7%	1%	3%	
Benton County	104,100	99,452	781	722	1,393	1,752	3,629
		96%	0.8%	0.7%	1%	2%	
Franklin County	34,200	29,442	1,401	228	418	2,711	5,147
		86%	4%	0.7%	1%	8%	

(a) The Other racial category is primarily a count of persons who marked "Other Race" on the 1980 census questionnaire and wrote in entries such as Cuban, Puerto Rican, Latino, Mexican, Dominican, etc. They represent persons who given an opportunity to identify themselves in a racial category did not select white (or any other category provided), but specifically identified themselves as being Mexican, Puerto Rican, Latino, etc. In 1980, this category represented a tabulation of 67,154 Spanish persons who considered themselves racially Spanish and some 9,402 additional responses that could not be elsewhere classified.

(b) Spanish Origin is not a race category; it may be viewed as a nationality group. Persons of Spanish Origin may be of any race and are counted in the other racial categories shown. In 1980, 44.4% of the persons who indicated they were of Spanish Origin identified themselves as being racially white; 47.6% selected the Other Races category. Very small percentages identified themselves as being black (1.3%), Indian (2.3%), or Asian (4.4%).

(c) Percentage figures refer to county, not state, populations.

Source: State of Washington, Office of Financial Management, Forecasting Division, Olympia, Washington.

The 1990 population estimates of Benton and Franklin counties show several factors that distinguish the population from Washington State's population. The population of Benton and Franklin counties is young with 48% of the total population under the age of 30 compared to 44% of the total state population. The largest age group in Benton and Franklin counties ranges from 0 to 4 years old, representing almost 10% of the total bicounty population, while the largest group in the state ranges from 30 to 34 years, which represents about 10% of the total state population.

4.5.4 Housing

In August 1990, nearly 88% of all housing (of 38,552 total units) in the Tri-Cities was occupied. Single-unit housing, which represents nearly 58% of the total units, has a 91% occupancy rate throughout the Tri-Cities. Multiple-unit housing, defined as housing with two or more units, has an occupancy rate of nearly 81%. Pasco has the lowest occupancy rate, 84%, in all categories of housing, followed by Richland, 87%, and Kennewick, 90%. Although representing only 7% of the housing unit types, mobile homes have the highest occupancy rate, nearly 93%. Table 4.5-3 shows a detailed listing of total units and occupancy rate by type in the Tri-Cities.

TABLE 4.5-3. Total Units and Occupancy Rates[a]

	All Units		Single Units		Multiple Units		Mobile Homes/ Trailers	
	Total	Rate, %	Total	Rate, %	Total	Rate, %	Total	Rate, %
Richland	13,841	87	8,840	93	4,585	74	416	100
Pasco	8,050	83	4,027	83	3,039	83	984	83
Kennewick	16,661	89	9,466	92	5,901	84	1,294	96
Tri-Cities Average	38,552	87	22,333	--	13,525	--	2,694	--

(a) Source: Personal communication with the Office of Financial Management, state of Washington. Data are calculations and estimations for 1990, based on data from the 1980 census, 1988 sample census, 1987 city census, and 1990 city census.

4.5.5 Transportation

The Tri-Cities serve as a regional transportation and distribution center with major air, land, and river connections. The Tri-Cities have direct rail service, provided by Burlington Northern and Union Pacific, connecting the area to more than 35 states. The Washington Central Railroad serves eastern Washington as well. Union Pacific operates the largest fleet of refrigerated rail cars in the United States and is essential to food processors that ship frozen food from this area. Passenger rail service is provided by Amtrak, which has a station in Pasco.

Docking facilities at the Ports of Benton, Kennewick, and Pasco are important aspects of this region's infrastructure. These facilities are located on the 525-km-long commercial waterway, made up of the Snake and Columbia rivers, extending from the Ports of Lewiston-Clarkston in Idaho to the deep-water ports of Portland, Oregon, and Vancouver, Washington. The average shipping time from the Tri-Cities to these deep-water ports by barge is 36 hours (Evergreen Community Development Association 1986).

Daily air passenger and freight services connect the area with most major cities through the Tri-Cities Airport, located in Pasco. The airport is currently served by two commuter-regional and two national airlines. The main runway is 2350 m in length and can accommodate landings and takeoffs by medium-range commercial aircraft, such as the Boeing 727-200 and Douglas DC-9. The Tri-Cities airport currently handles about 145,000 passengers per year. Projections indicate that the recently expanded terminal can serve almost 250,000 passengers annually. Two additional airports, located in Richland and Kennewick, are limited to serving private aircraft.

The Tri-Cities are linked to the region by five major highways. Route 395 joins the area with Spokane to the northeast. Both it and Route 240, which crosses through the Hanford Site, connect with Interstate 90 to the north. Route 12 links the region with Yakima to the northwest; with Lewiston, Idaho, to the east; and with Walla Walla to the southeast. The area is also linked to Interstate 84 to the south, via Interstate 82, and Route 14 and Interstate 82 also connects the area to the Yakima Valley and Interstate 90 in

Ellensburg. Routes 240 and 24 traverse the Hanford Site and are maintained by Washington State. Other roads within the reservation are maintained by the DOE.

4.5.6 Educational Services

Primary and Secondary. Primary and secondary education are served by the Richland, Kennewick, Pasco, and Kiona-Benton school districts. The combined 1990 spring enrollment for all districts was approximately 27,000 students. This total consists of approximately 11,000 students from the Kennewick school district, and about 7,100 and 7,300 students, respectively, in the Richland and Pasco school districts. In 1987, the Kennewick and Pasco school districts were operating near or at their capacity. This is not the case with the Richland District, where enrollment peaked at 8,700 in the early 1980s. By opening schools that closed in the last several years, the Richland School District could expand enrollment by about 30%. In 1989, the district's occupancy rate had increased to about 90%.

Post-Secondary. Post-secondary education in the Tri-Cities area is provided by a junior college, Columbia Basin College, and the Tri-Cities branch campus of Washington State University (WSU-TC). The WSU-TC offers a variety of upper-division, undergraduate, and graduate degree programs. In 1990, enrollment at these two institutions was approximately 7,200 students, with a capacity for about 23,000 students. Many of the programs offered by these two institutions are geared toward the vocational and technical needs of the area. Eight undergraduate and 14 graduate programs are currently available.

4.5.7 Health Care and Human Services

The Tri-Cities have three major hospitals and four minor emergency centers. All three hospitals offer general medical services and include a 24-hour emergency room, basic surgical services, intensive care, and neonatal care.

Kadlec Medical Center, located in Richland, has 144 beds and is functioning at a 40% occupancy rate. The 5000 admissions in 1989 represent 45% of the number of occupancies for all three hospitals. About 60%, or 3000, of these admissions are non-Medicare/Medicaid patients who average 3.5 days per admission.

Kennewick General Hospital maintains a 45% occupancy rate of its 71 beds with nearly 3100 annual admissions. Non-Medicare/Medicaid patients in 1989 represented 50% of total admissions.

Our Lady of Lourdes Hospital, located in Pasco, recently increased its occupancy rate to 45% of its 108 beds. The hospital performs a significant amount of outpatient care, which serves as the primary source of income for the hospital. In 1989, Our Lady of Lourdes had about 3100 admissions, of which 65% were non-Medicare/Medicaid patients.

Human Services. The Tri-Cities offer a broad range of social services. State human service offices in the Tri-Cities include the Job Services office of the Employment Security Department; Food Stamp offices; the Division of Developmental Disabilities; Financial and Medical Assistance; the Child Protective Service; emergency medical service; a senior companion program; and vocational rehabilitation.

The Tri-Cities are also served by a large number of private agencies and voluntary human services organizations. The United Way, an umbrella fund-raising organization, has proposed contributions of $2.8 million in 1990 to its member agencies throughout the area. These member agencies had a cumulative budget total of $17.3 million in 1990 (United Way 1989).

4.5.8 Police and Fire Protection

Police protection in Benton and Franklin counties is provided by Benton and Franklin counties' sheriff departments, local municipal police departments, and the Washington State Patrol Division headquartered in Kennewick.

Table 4.5-4 shows the number of commissioned officers and patrol cars in each department in 1988. The Kennewick, Richland, and Pasco municipal departments maintain the largest staffs of commissioned officers with 49, 42, and 39, respectively. Table 4.5-5 indicates the number of fire-fighting personnel, both paid and volunteer, on the staffs of fire districts in the area.

TABLE 4.5-4. Police Personnel in the Tri-Cities, 1990

	Commissioned Officers	Patrol Cars
Kennewick Municipal	49	22
Pasco Municipal	39	11
Richland Municipal	42	12
West Richland Municipal	8	8
County Sheriff, Benton County	30	50
County Sheriff, Franklin County	16	24

Source: Personal communication with each department office, August 1990.

TABLE 4.5-5. Fire Protection in the Tri-Cities, 1990

	Fire Fighting Personnel	Volunteers	Total	Service Area
Kennewick	45	0	45	City of Kennewick
Pasco	21	0	21	City of Pasco
Richland	41	0	41	City of Richland
BCRFD 1	2	100	100	Kennewick Area
BCRFD 2	0	31	31	Benton City
BCRFD 4	2	28	30	West Richland

Source: Personal communication with each department office, August 1990.

In Benton County, violent crimes occurred in 1989 at a rate of 3.0 per year per 1000 residents and property crimes at 56.3 per year per 1000 residents. Table 4.5-6 illustrates that both violent and property crimes occurred at a lesser rate in Richland than in Kennewick. Pasco violent crime and property crime rates were the highest of the Tri-Cities at 10.2 per 1000 residents and 129.9 per 1000 residents, respectively.

TABLE 4.5-6. Violent and Property Crimes

	Violent Crimes per 1000 Residents	Property Crimes per 1000 Residents
Benton County	3.0	56.3
Richland	0.9	40.1
Kennewick	3.0	91.9
Franklin County	6.1	83.7
Pasco	11.1	137.6
Yakima County	6.0	83.6
Spokane County	4.0	63.4
Washington State	4.8	62.5

Source: Personal communication with Washington Association of Sheriffs and Police Chiefs, August 1990.

The Benton County's violent crime rate per 1000 residents was slightly below those of Washington State, while Franklin County's rate exceeds the Washington State rates.

Hanford Fire Station. The Hanford Fire patrol, composed of 116 fire fighters, is trained to dispose of hazardous waste and to fight chemical fires. During the 24-hour duty period, 7 fire fighters cover the 1100 and 300 Areas, 7 protect the 300-East and 200-West areas, 6 watch the 400 Area and the Washington Public Power Supply Service (WPPSS) area, and 6 are responsible for the 100 Area. To perform their responsibilities, each station has access to a Hazardous Material Response Vehicle that is equipped with chemical fire extinguishing equipment, an attack truck that carries foam, halon, and Purple-K dry chemical, a mobile air truck that provides air for gas masks, and a transport tanker that supplies water to six brush trucks.

4.5.9 Parks and Recreation

The convergence of the Columbia, Snake, and Yakima rivers offers the residents of the Tri-Cities a variety of recreational opportunities.

The Lower Snake River Project includes Ice Harbor Lower Monumental, Little Goose, Lower Granite locks and dams, and a levee system and parkway at Clarkston and Lewiston. While navigation capabilities and the electrical output represent the major benefits of this project, recreational benefits have also resulted. The Lower Snake River Project provides boating, camping, and picnicking facilities in nearly a dozen different areas along the Snake River. In 1986, nearly 385,000 people visited the area and participated in activities along the river.

Similarly, the Columbia River provides ample water recreational opportunities on the lakes formed by the dams. Lake Wallula, formed by McNary Dam, offers a large variety of parks and activities, which attracted more than 3 million visitors in 1986. The Columbia River Basin is also a popular area for migratory waterfowl and upland game bird hunting.

Other opportunities for recreational activities in the Tri-Cities are accommodated by the indoor and outdoor facilities available, as described in Table 4.5-7. Numerous tennis courts, ball fields, and golf courses offer outdoor recreation to residents and tourists. Several privately owned health clubs in the area offer indoor tennis and racquetball courts, pools, and exercise programs. Bowling lanes and roller skating rinks also serve each of the Tri-Cities.

4.5.10 Utilities

Water. The principal source of water in the Tri-Cites and the Hanford Site is the Columbia River from which the water systems of Richland, Pasco, and Kennewick draw a large portion of the average 1 million m^3 necessary each day. Each city operates its own supply and treatment system.

The Richland water supply system derives 83% of its water from the Columbia River and the remaining 17% from groundwater wells. The city of Richland's total usage in 1989 was 16.71 million m^3 (residential,

TABLE 4.5-7. Examples of Physical Recreational Facilities Available in the Tri-Cities[(a)]

	Facilities
Tennis	62 outdoor courts (e.g., Sylvester Park, Howard Amon Park, Pasco High School). Indoor courts at Tri-City Court Club and Columbia Basin Racquet Club.
Golf	Six courses including Tri-City Country Club, Canyon Lakes, and West Richland Municipal Golf Course. Several driving ranges and pro shops are also available.
Bowling	Lanes in each city including Atomic Bowling Center, Clover Leaf Lanes, and Columbia Lanes.
Swimming	Private (e.g., Ranchette Estates, Oasis Water Park) and public (e.g., Richland, Pasco, Kennewick) swimming pools in the area. Boating, water-skiing, and swimming on the Columbia River in the Tri-Cities area.
Ball	Baseball fields and basketball courts are located through out the Tri-Cities including Badger Canyon, Craighill Playgrounds, Stevens Playground and Lewis and Clark School. Soccer and football fields are also located in various areas.
Skating	Rollerskating, iceskating, and skateboard facilities.
Camping	Several hundred campsites within driving distance from the Tri-Cities area including Levy Park, Fishhook Park, and Sun Lakes.
Fishing	Steelhead, sturgeon, trout, walleye, bass, and crappie fishing in the lakes and rivers near the Tri-Cities area.
Hunting	Duck, geese, pheasant, and quail hunting. Deer and elk hunting in the Blue Mountains and the Cascade Range.

(a) Source: Watson et al. (1984).

9.65 million m^3; industrial and commercial, 5.87 million m^3; government and schools, 1.19 million m^3). This current usage represents approximately 45% of the maximum supply capacity. The city of Pasco system likewise draws from the Columbia River for its water needs. The 1989 estimates of production are 7.57 million m^3. The Kennewick system uses two wells and the Columbia River for its supply. These wells serve as the sole source of water between November and March and can provide approximately 60% of the total maximum supply of 33.2 million m^3. The 1989 usage was billed at 9.84 million m^3.

The major incorporated areas of Benton and Franklin counties are served by municipal wastewater treatment systems, whereas the unincorporated areas are served by onsite septic systems. Richland's wastewater treatment system is designed to treat a total capacity of 27 million m^3/yr. In 1989, the system processed more than 6.6 million m^3. The Kennewick system, similarly, has significant excess capacity. With a treatment capability of 12 million m^3/yr, current usage is just over 56% at 6.70 million m^3 annually. Pasco's waste treatment system processes over 3 million m^3 each year; the system could treat 34.6 million m^3.

Electricity. In the Tri-Cities, electricity is provided by the Benton County Public Utility District, Benton Rural Electrical Association, Franklin county Public Utility District, and City of Richland Energy Services Department. All the power that these utilities provide in the local area is purchased from the Bonneville Power Administration (BPA), a federal power marketing agency. The average rate for residential customers served by the three local utilities is roughly $0.035/kWh. Electrical power for the Hanford Site is purchased wholesale from BPA. Energy requirements for the Site during FY 1988 exceeded 550 average MW.

Natural gas serves a small portion of residents, with 3100 residential customers in June of 1989.

In the Pacific Northwest, hydropower, and to a lesser extent, coal and nuclear power, make up the region's electrical generation system. Total nameplate generating capacity is about 43,360 MW. Approximately 75% of the region's installed generating capacity is hydroelectric, which supplies approximately 70% of the electricity used by the region. Coal-fired generating capacity is 6,300 MW in the region, or 15% of the region's electrical generating capacity. Oil and natural gas account for about 1,540 MW of capacity. The Hanford Generating Project had been operated with by-product steam produced by the N Reactor, and provided 800 MW (net) until the N Reactor was shut down.

The region's electrical power system, more than any other system in the nation, is dominated by hydropower. On average, the region's hydropower system can produce 16,400 MW. Variable precipitation and limited storage capabilities alter the system's output from 12,300 average MW under critical water conditions to 20,000 average MW in record high water years. The Pacific Northwest system's reliance on hydroelectric power means that it is more constrained by the seasonal variations in peak demand than in meeting momentary peak demand.

In 1988, the surplus was about 1400 MW, based on medium estimates. This surplus has been decreasing quickly, dropping 1100 MW between 1986 and 1988. The projects currently under construction in the Northwest include about 150 MW of new capacity (Northwest Power Planning Council 1986).

4.5.11 Land Use

The Hanford Site encompasses 1450 km^2 and includes several DOE operational areas. The major areas are as follows:

- The entire Hanford Site has been designated a National Environmental Research Park (NERP).
- The 100 Areas, bordering on the right bank (south shore) of the Columbia River, are the sites of the eight retired plutonium production reactors and the N Reactor, which is currently in wet lapp. The 100 Areas occupy about 11 km^2.
- The 200-West and 200-East Areas are located on a plateau about 8 and 11 km, respectively, from the Columbia River. These areas have been dedicated for some time to fuel reprocessing and waste processing management and disposal activities. The 200 Areas cover about 16 km^2.
- The 300 Area, located just north of the City of Richland, is the site of nuclear research and development. This area covers 1.5 km^2.
- The 400 Area is about 8 km north of the 300 Area and is the site of the Fast Flux Test Facility used in the testing of breeder reactor systems. Also included in this area is the Fuels and Material Examination Facility.
- The 600 Area includes all of the Hanford Site not occupied by the 100, 200, 300, or 400 Areas. Land uses within the 600 Area include:

1. 310 km^2, known as the Arid Land Ecology Reserve (ALE), which has been set aside for ecological studies.

2. 4 km^2 leased by Washington State, a part of which is used for commercial low-level radioactive waste disposal.

3. 4.4 km^2 for Washington Public Power Supply System nuclear power plants.

4. 2.6 km^2 transferred to Washington State as a potential site for the disposal of nonradioactive hazardous wastes.

5. About 130 km^2 under revocable use permit to the U.S. Fish and Wildlife Service for a wildlife refuge.

6. 225 km^2 under revocable use permit to the Washington State Department of Game for recreational game management.

7. Support facilities for the controlled access areas.

An area of 665 km^2 has been designated for ALE, the U.S. Fish and Wildlife Service, wildlife refuges, and the Washington State Department of Game management area (DOE 1986).

Land use in other areas includes urban and industrial development, irrigated and dry-land farming, and grazing. In 1985, wheat represented the largest single crop in terms of area planted in Benton and Franklin counties with 116,000 hectares. Corn, alfalfa, hay, barley, and grapes are other major crops in Benton and Franklin counties.

In 1986, the Columbia Basin Project, a major irrigation project to the north of the Tri-Cities, produced gross crop returns of $343 million, representing 19% of all crops grown in Washington State. In 1986, the average gross crop value per irrigated acre was $664.00. The largest percentage of irrigated acres produced: alfalfa hay, 29.4% of irrigated acres; wheat, 15.0%, corn (feed grain), 9.4%. Other significant crops are potatoes, apples, dry beans, asparagus, and pea seed.

4.5.12 Offsite Historical and Cultural Sites

Currently, 16 archaeological properties are located near the Hanford Site. These properties are listed in the National Register of Historic Places.

4.5.13 Visual Resources

The land in the vicinity of the Hanford Site is generally flat with little relief. Rattlesnake Mountain, rising to 1060 m above mean sea level, forms the western boundary of the site, and Gable Mountain and Gable Butte are the highest land forms within the site. Both the Columbia River, flowing across the northern part of the site and forming the eastern boundary, and the spring-blooming desert flowers provide a visual source of enjoyment to people. The White Bluffs, steep bluffs above the northern boundary of the river in this region, are a striking feature of the landscape.

4.6 NOISE

Noise is technically defined as sound waves perceptible to the human ear. Sound waves are characterized by frequency, measured in Hertz (Hz), and sound pressure expressed as decibels (dB). Humans have a perceptible hearing range of 31 to 20,000 Hz. The decibel is a value equal to 10 times the logarithm of the ratio of a sound pressure squared to a standard reference sound pressure level (20 micropascals) squared. The threshold of audibility ranges from about 60 dB at a frequency of 31 Hz to about less than 1 dB between 900 and 8,000 Hz. [For regulatory purposes, noise levels for perceptible frequencies are weighted to provide an A-weighted sound level (dBA) that correlates highly with individual community response to noise]. Sound pressure levels outside the range of human hearing are not considered noise in a regulatory sense, even though wildlife may be able to hear at these frequencies.

Noise levels are often reported as the equivalent sound level (Leq). The Leq is expressed in A-weighted (dBA) over a specified period of time, usually 1 or 24 hours. The Leq expresses time-varying noise levels by integrating noise levels over time and expressing them at a steady-state continuous sound level.

4.6.1 Background Information

Studies at Hanford of the propagation of noise have dealt primarily with occupational noise at work sites. Environmental noise levels have not been extensively evaluated because of the remoteness of most Hanford activities and isolation from receptors that are covered by federal or state statutes. This discussion focuses on what few environmental noise data are available. The majority of available information consists of model predictions, which in many cases has not been verified because the predictions indicated that the potential to violate state or federal standards is remote or unrealistic.

4.6.2 Environmental Noise Regulations

The Noise Control Act of 1972 and its subsequent amendments (Quiet Communities Act of 1978, 42 USC 4901-4918, 40 CFR 201-211) direct the regulation of environmental noise to the state. The State of Washington has adopted RCW 70.107, which authorizes the Department of Ecology to implement rules consistent with federal noise control legislation. RCW 70.107 and the implementing regulations embodied in WAC 173-60 through 173-70 defined the regulation of environmental noise levels. Maximum noise levels are defined for the zoning of the area for environmental designation for noise abatement (EDNA). The Hanford Site is classified as a Class C EDNA on the basis of industrial activities. Unoccupied areas are also classified as Class C areas by default because they are neither Class A (residential) or Class B (commercial). Maximum noise levels are established based on the EDNA classification of the receiving area and the source area (Table 4.6-1).

4.6.3 Hanford Site Sound Levels

Most industrial facilities on the Hanford Site are located far enough away from the site boundary that noise levels at the boundary are not measurable or are barely distinguishable from background noise levels. Modeling of environmental noises has been performed for commercial reactors and State Highway 240 through the Hanford Site. These data are not concerned with background levels of noise and are not reviewed here. There are two sources of measured environmental noise at Hanford. Environmental noise measurements were made in 1981 during site characterization of the Skagit/Hanford Nuclear Power Plant Site (NRC 1982). The Hanford Site was considered as the site for a geologic waste repository (Basalt Waste Isolation Project, BWIP) for spent commercial nuclear fuel and other high-level nuclear waste. Site characterization studies performed in 1987 included measurement of

TABLE 4.6-1. Applicable State Noise Limitations for the Hanford Site Based on Source and Receptor EDNA Designation (values are dBA)

Source	Receptor		
Hanford Site	Class A Residential	Class B Commercial	Class C Industrial
Class C - Day	60	65	70
Night	50	--	--

background environmental noise levels at five sites on the Hanford Site. Additionally, certain activities such as well drilling and sampling have the potential for producing noise in the field apart from major permanent facilities.

Skagit/Hanford Data

Preconstruction measurements of environmental noise were taken in June of 1981 on the Hanford Site (NRC 1982). Fifteen sites were monitored and noise levels ranged from 30 to 60.5 dBA (Leq). The values for isolated areas ranged from 30 to 38.8 dBA. Measurements taken around the sites where the Supply System was constructing nuclear power plants (WNP-1, WNP-2, and WNP-4) ranged from 50.6 to 64 dBA. Measurements taken along the Columbia River near the intake structures for WNP-2 were 47.7 and 52.1 dBA compared to more remote river noise levels of 45.9 dBA (measured about 3 miles upstream of the intake structures). Community noise levels in North Richland (3000 Area at Horn Rapids Road and the By-Pass Highway) were 60.5 dBA.

BWIP Data

Background noise levels were determined at five sites located within the Hanford Site. Noise levels are expressed as equivalent sound levels for 24 hours (Leq-24). Sample location date, and Leq-24 are listed in Table 4.6-2. Wind was identified as the primary contributor to background noise levels with winds exceeding 12 mph significantly affecting noise levels. Coleman concludes that background noise levels in undeveloped areas at Hanford can best be described as a mean Leq-24 of 24 to 36 dBA. Periods of high wind, which normally occur in the spring, would elevate background noise levels.

TABLE 4.6-2. Background Noise Levels Measured at Isolated Areas

Site	Location			Date	Leq-24 (dBA)
	Sec.	Range	Township		
1	9	R25E	T12N	07-10-87	41.7
				07-11-87	40.7
				07-12-87	36.0
				07-13-87	37.2
				07-14-87	35.6
2	26	R25E	T13N	07-25-87	43.9
				07-26-87	38.8
				07-27-87	43.8
				07-28-87	37.7
				07-29-87	43.2
3	18	R26E	T12N	08-08-87	39.0
				08-09-87	35.4
				08-10-87	51.4[a]
				08-11-87	56.7[a]
				08-12-87	36.0
4	34	R27E	T11N	09-09-87	35.2
				09-10-87	34.8
				09-11-87	36.0
				09-12-87	33.2
				09-13-87	37.3
5	14	R28E	T11N	10-15-87	40.8
				10-16-87	36.8
				10-17-87	33.7
				10-18-87	31.3
				10-19-88	35.9

(a) Leq includes grader noise.

Noise Levels of Hanford Field Activities

In the interest of protecting Hanford workers and complying with (OSHA) standards for noise in the workplace, the Hanford Environmental Health Foundation has monitored noise levels resulting from several routine operations performed at Hanford. Occupational sources of noise propagated in the field have been summarized in Table 4.6-3. These levels are reported here because operations such as well sampling are conducted in the field away from established industrial areas and have the potential for disturbing sensitive wildlife.

TABLE 4.6-3. Monitored Levels of Noise Propagated from Outdoor Activities at the Hanford Site[a]

Activity	Average Noise Level	Maximum Noise Level	Year Measured
Water wagon operation	104.5	111.9	1984
Well sampling	74.8 - 78.2		1987
Truck	78 - 83		1989
Compressor	88 - 90		
Generator	93 - 95		
Well drilling, Well 32-2	98 - 102	102	1987
Well drilling, Well 32-3	105 - 11	120 - 125	1987
Well drilling, Well 33-29	89 - 91		1987
Pile driver (diesel 5 ft from source)	118 - 119		
Tank farm filter building (30 ft from source)	86		1976

(a) Noise levels measured in decibels (dB).

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5.0 MODELS USED TO ESTIMATE ENVIRONMENTAL IMPACTS

Potential and/or realized environmental impacts from nuclear materials at the Hanford Site are evaluated using a wide assortment of computer programs. The programs described in this chapter contain mathematical models written in FORTRAN. Most of these programs operate on one or more medium-size computer systems such as VAX 11/780, UNIVAC 1110 series, CDC 6600-7600 series, or DEC PDP 11, although several of the radiation dosimetry programs have been written for IBM personal computers. Most of the programs are well documented and include source-code listings and special instructions for computer users. The use of a modular programming format and restricted use of machine-dependent code also appear to be characteristic of most programs. These features allow for easier modification (or upgrading) of the codes and generally increase program transportability.

A summary of the computer programs described in this chapter is provided in Table 5.1. Most of the programs contain mathematical models that fall into one of three generic categories: radiation dose models (13 programs), groundwater transport models (9 programs), or atmospheric dispersion models (1 program).

Radiation dose models are used to calculate dose to selected targets (e.g., organs, individuals, or populations) from all major environmental pathways (i.e., air, soil, water, and food chain). Calculations may be performed for both acute (one-time) and chronic (single years, human life-times, or thousands of years) exposures. Three types of radiation doses are generally reported:

- 1-year dose: the population or individual dose resulting from 1 year of external plus internal exposure
- committed dose: the population or individual dose resulting from 1 year of external and internal exposure plus the continued internal dose accumulated from that year's combined inhalation and ingestion exposure
- accumulated dose: the population or individual dose (external plus internal) accumulated over a lifetime (usually 50 or 70 years).

TABLE 5.1. Summary of Computer Programs

Program	Category	Description or Primary Use
AIRDOS-EPA	Radiation Dose	Calculates maximum individual and population dose for chronic releases
ALLDOS	Radiation Dose	Calculates maximum individual and population dose tables for chronic and acute releases
ARRRG	Radiation Dose	Dose from aquatic pathways
BIOPORT/MAXI1	Radiation Dose	Dose from biotic transport processes
CFEST	Groundwater Transport	Coupled fluid, energy, and solute transport in confined aquifers
CHAINT	Groundwater Transport	Radionuclide transport in a fractured porous medium
DACRIN	Radiation Dose	Inhalation dose to individuals from acute or chronic releases
DITTY	Radiation Dose	Collective population dose over a 10,000-year period
FE3DGW	Groundwater Transport	Three-dimensional, finite-element, saturated flow model
FOOD	Radiation Dose	Dose from terrestrial pathways
GENII	Radiation Dose	Second generation of Hanford dosimetry codes
GETOUT	Groundwater Transport	Radionuclide transport through geologic media
ISC	Atmospheric Dispersion	Performs atmospheric dispersion calculations and assesses air quality impacts associated with an industrial source complex
ISOSHLD	Radiation Shielding	Performs gamma-ray shielding calculations

TABLE 5.1. (contd)

Program	Category	Description or Primary Use
KRONIC	Radiation Dose	External individual and population annual dose from chronic releases
MAGNUM-2D	Groundwater Transport	Two-dimensional, coupled heat transfer and groundwater flow in a fractured porous medium
MMT	Groundwater Transport	Radiocontaminant transport in saturated and unsaturated soils
ONSITE/MAXI1	Radiation Dose	Evaluates human intrusion scenarios at low-level radioactive waste sites
ORIGEN2	Radionuclide Inventory	Radionuclide generation and decay code
PABLM	Radiation Dose	Calculates internal radiation doses from external exposure and food pathways
PORFLO	Groundwater Transport	Continuum model for fluid flow, heat transfer, and mass transport in porous media
RADTRAN III	Radiation Dose	Health and economic impacts associated with transportation of radioactive materials
SUBDOSA	Radiation Dose	External doses to individuals from acute releases of radiation
TRANSS	Groundwater Transport	One-dimensional groundwater transport model
UNSAT-H	Groundwater Transport	Unsaturated flow model
VTT	Groundwater Transport	Simulates flow in multilayered aquifer systems

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A significant upgrade of the radiation dosimetry programs used at Hanford was completed in 1988 as part of the Hanford Environmental Dosimetry Upgrade Project. The new Hanford Environmental Dosimetry System, called Generation II or GENII, provides an integrated package of codes based on existing Hanford models and codes, but includes updated formulations and transfer coefficients. GENII essentially replaces many of the previously used dosimetry programs, including AIRDOS-EPA, ALLDOS, ARRRG, BIOPORT/MAXI, DACRIN, DITTY, FOOD, ISOSHLD, KRONIC, ONSITE/MAXI, PABLM, AND SUBDOSA. Separate documentation has been provided for these programs in Appendix B.

The groundwater programs described in this chapter actually include a rather wide assortment of hydrologic and hydrogeochemical models. They are used primarily to simulate subsurface flow (saturated and/or unsaturated) and heat and solute transport through geologic media (i.e., soils, fractured rock). Most have been designed to accommodate the unique geologic and climatic features (i.e., flood basalts, arid conditions) that characterize the Hanford Site. They range in sophistication (i.e., size, speed, and cost of operation, graphics capabilities, etc.) from relatively simple one-dimensional models, to more complex two- and three-dimensional models.

The Industrial Source Complex (ISC) model is the only atmospheric dispersion model considered in this chapter; however, it should be noted that many of the radiation dose programs also perform atmospheric dispersion calculations.

Listings for each of the programs appearing in this chapter include 1) a <u>general description</u> with a summary of the key features and primary application of each program, 2) a list of important <u>assumptions and/or limitations</u> that apply to each program, 3) special <u>programming considerations</u>, including the software and hardware compatibility of the current version of the program and, if applicable, a list of supplemental documentation, such as user's guides, 4) a <u>current contact</u> with a name and address of an individual (or agency) who can provide updated information on a particular program, and 5) a listing of all relevant <u>source</u> documentation for each program. A current contact may not be listed for programs that are not in current usage or in cases in which the principal program author(s) cannot be contacted or is no longer involved with the program. Programs falling into this category have been listed in Appendix A.

In most cases this information has been taken directly from the abstracts, summaries, or introductory sections of the original program documentation. Previous summaries of computer programs (e.g., EPA 1978; NRC 1982; Strenge et al. 1976) were also used in the preparation of this chapter. Because many programs undergo frequent revision, material documenting their mathematical models and/or computer implementation is often out of date a short time after it is released. Therefore, readers are urged to check with the current contacts if in doubt about the capabilities of a particular program.

Finally, the measurement of uncertainty in the evaluation of model performance deserves special mention. Models use mathematical analogs to describe complex physical and/or chemical processes and, for this reason, often provide a greatly simplified view of the "real world." The ability of a model to provide an accurate simulation of a particular process is dependent on many factors. For instance, errors can result from 1) invalid assumptions concerning key model parameters (i.e., boundary conditions, dispersion characteristics, etc.), 2) the use of inappropriate or overly simplistic analogs, 3) calculational errors in the computer codes, and 4) basic inadequacies in the input data. In some cases program performance may be significantly improved by more rigorous sampling, but additional data collection or analysis is often impractical because of time and cost constraints. Serious errors can also arise from model misuse or misinterpretation of program output. Computer programs are designed for specific applications, and users must be aware of their limitations. Consultation with the program author(s) or an experienced user should serve to avoid most problems of this nature.

There are several standard procedures for testing the veracity of mathematical models and the computer programs that use them. Model <u>verification</u> involves comparing program output with results generated by hand calculations. Most models are thoroughly verified during the normal course of program development. Program output may also be compared with results from a related, and usually previously verified, model. This is referred to as benchmarking. The most rigorous test of model uncertainty includes some form of field validation. This involves testing model predictions against actual field data or data obtained from laboratory experiments, which simulate conditions similar to those the program was designed to evaluate. Field validation is not an absolute test of model accuracy, however, and great care should be taken in interpreting the results from these kinds of studies. For the most part, validation studies only provide a limited assessment of model performance (i.e., results may only apply to the conditions defined for the test case). Models used to predict long-term trends (e.g., 10,000-year dose) or impacts resulting from postulated accidents generally cannot be validated. Nevertheless, validation studies provide an additional level of confidence that is highly desirable for engineers, scientists, and management personnel who must make decisions regarding the selection and operation of computer programs used in environmental assessment.

An attempt has been made to acknowledge any verification or validation studies that are cited in the original documentation for each of the programs described in this chapter. Regrettably, unpublished work and/or studies appearing in subsequent or supplemental documents may have been overlooked.

5.1 AIRDOS-EPA

AIRDOS-EPA is part of a series of programs (presently called CAP-88) developed by ORNL for EPA to implement the atmospheric assessment required by the clean air act.

The AIRDOS-EPA program is used to estimate radionuclide concentrations in air; rates of deposition on ground surfaces; ground surface concentrations; and intake rates via inhalation of air and ingestion of vegetables, milk, and meat from airborne releases of up to 36 radionuclides. In addition radiation doses to populations and individuals are estimated using the calculated concentrations. A modified Gaussian plume equation is used to estimate both horizontal and vertical dispersion of up to 36 radionuclides released from one to six stacks or area sources.

Dose conversion factors are input to the program, and doses for each distance and direction from the source specified by the user are estimated for total body, red marrow, lungs, endosteal cells, stomach wall, lower large intestine wall, thyroid, liver, kidneys, testes, and ovaries through the following paths: air submersion, inhalation, ground irradiation, immersion in water (deposition into swimming pools), and ingestion of food products produced in the region.

The other programs of this series are PREPARE - a preprocessor that assists the user in preparing the input file to AIRDOS (Sjoreen and Miller 1984), DARTAB - a program to estimate risk factors from the output results of AIRDOS (Begovich et al. 1981), PREDATA - a preprocessor to create DARTAB input data sets, and RADFMT - a utility to convert RADRISK.BCD (a data file of dose and risk factors for use by DARTAB) to binary.

<u>Assumptions and/or Limitations</u>

- Straight-line Gaussian plume dispersion model used with Pasquill dispersion coefficients calculated using Brigg's equations (Gifford 1976)
- Plume rise (both momentum and buoyancy terms) and downwash corrections calculated or user plume rise accepted
- Plume depletion calculated for both wet and dry deposition

- Gravitational settling included
- Area sources supported
- Radionuclide concentrations in fresh vegetables, milk, and meat are estimated using the models that Soldat developed for the NRC (found in Regulatory Guide 1.109)
- Programs limited to 36 nuclides, 20 downwind distances, and 16 directions.

Programming Considerations

The program is written in FORTRAN IV using the IBM 3081 or 3033 running under the OS/VMS operating system and FORTRAN 77 for the DEC VAX running under VMS.

Current Contact

K. C. Rhoads, K3-54
Batte1le, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-375-6832

Sources

Begovich, K. F., K. F. Eckerman, E. C. Schlatter, S. Y. Ohr, and R. O. Chester. 1981. DARTAB, A Program to Combine Airborne Radionuclide Environmental Exposure Data with Dosimetric and Health Effects Data to Generate Tabulations of Predicted Health Impacts. ORNL-5692, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Moore, R. E., C. S. Baes III, L. M. McDowell-Boyer, A. P. Watson, F. O. Hoffman, J. C. Pleasant and C. W. Miller. 1977. AIRDOS-EPA: A Computerized Methodology for Estimating Environmental Concentrations and Dose to Man from Airborne Releases of Radionuclides. ORNL-5532, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Sjoreen, A. L., and C. W. Miller. 1984. PREPAR - A User-Friendly Pre-processor to Create AIRDOS-EPA Input Data Sets. ORNL-5952, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

5.2 CFEST

The CFEST (Coupled Fluid, Energy, and Solute Transport) program was developed for the U.S. Department of Energy (DOE) as part of the Underground Energy Storage (UES) Program's effort to study the potential use of natural aquifers as hosts for thermal energy storage and retrieval. CFEST provides a multidimensional analysis of coupled fluid, energy, and solute transport and is used to model nonisothermal events in a confined aquifer system.

The program employs a standard Galerkin finite-element methodology and is intended to provide a simulation capability for the evaluation of experimental designs and field data. The program only considers single-phase, Darcian flows but can handle both steady-state and dynamic simulations. Flows are simulated in either a horizontal plane, a vertical plane, or a fully three-dimensional region within a Cartesian coordinate system. An option also exists for the axisymmetric analysis of a vertical cross section. The program currently employs the bilinear quadrilateral element in all two-dimensional analyses and the trilinear quadrilateral solid in three-dimensional simulations.

CFEST is an extension of the Finite-Element Three-Dimensional Groundwater (FE3DGW, Subsection 5.3) program. The program is highly interactive and employs a staged execution structure.

Assumptions and/or Limitations

The following assumptions have been incorporated in the CFEST program:

- The flow is transient and laminar (Darcian).
- The permeability and coordinate axes are collinear. The rotation of elements to anisotropy axes is not performed. Finite-element formulations, in general, permit such a rotation. In aquifer problems, horizontal dimensions are far greater than vertical. Therefore, variation between anisotropy axes and the coordinate axes is not significant for regional models. Moreover, field data are also limited by anisotropy properties.
- Fluid density is a function of pressure, temperature, and solute concentration.
- Fluid viscosity is a function of temperature and concentration.

- The injected fluid is miscible with the resident aquifer fluids.

- Aquifer properties (i.e., porosity, permeability, and thickness) vary spatially. The thickness variations are nodal while material properties are element constant.

- Hydrodynamic dispersion is a function of fluid velocity.

- Boundary conditions permit natural water movement in the aquifer; heat losses/gains to adjacent formations; and the location of injection, production, and observation wells anywhere within the system.

- The porous medium and fluid are compressible.

- The fluid and porous media are in thermal equilibrium.

- Rock density and heat capacity remain constant.

- Viscous dissipation is negligible with respect to the energy balance.

- Verification and/or validation studies. CFEST has been the subject of extensive verification efforts (see Chapter 4.0 in Gupta et al. 1982). Solutions have been obtained for a wide range of problems within three broad categories: 1) flow prediction tests (steady and unsteady drawdown in a confined aquifer, unsteady drawdown in a leaky confined aquifer, uniform regional flow with sources and sinks), 2) energy and solute mass transport verifications (Dirichlet upstream boundary condition, mixed upstream boundary condition, approximate analytical solution to an axisymmetric analysis including radially varying velocity), and 3) energy transport including cap and bedrock conduction (Avdonin's radial problem, Avdonin's linear problem, Gringarten-Sauty problem).

Programming Considerations

CFEST is written in FORTRAN and runs on DEC PDP 11/70 computers.

Current Contacts

Charles T. Kincaid, K6-77
Battelle, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-376-8324

Charles R. Cole
Battelle, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-376-8451

Sources

Cole, C. R., S. B. Yabusaki, and C. T. Kincaid. 1988. CFEST-SC, Coupled Fluid Energy, and Solute Transport Code, SuperComputer Version, Documentation and User's Manual. Battelle, Pacific Northwest Laboratories, Richland, Washington.

Gupta, S. K., C. R. Cole, C. T. Kincaid, and A. M. Monti. 1987. Coupled Fluid, Energy, and Solute Transport (CFEST) Model: Formulation and Users Manual. Prepared for the U.S. Department of Energy by Battelle Project Management Division, Office of Nuclear Waste Isolation, Columbus, Ohio, and Pacific Northwest Laboratory, Richland, Washington.

Gupta, S. K., C. T. Kincaid, P. R. Meyer, C. A. Newbill, and C. R. Cole. 1982. A Multi-Dimensional Finite Element Code for the Analysis of Coupled Fluid, Energy and Solute Transport (CFEST). PNL-4260, Pacific Northwest Laboratory, Richland, Washington.

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5.3 FE3DGW

FE3DGW (Finite-Element, Three-Dimensional Ground-Water Flow Model) contains a three-dimensional, finite-element hydrologic model that simulates saturated groundwater flow in a homogeneous or heterogeneous geologic system. The program was developed to anticipate the response of a flow system to natural recharge from rain and various expected and proposed stresses of pumping and/or recharge through wells and streams. FE3DGW defines the groundwater flow field and provides water flow paths and travel times.

FE3DGW can simulate single-layer systems with variable thickness or multilayered systems; thickness can be varied, and also the number of layers can be changed to agree with the vertical geologic section. Variable spacing may be used and source or sink terms can be defined at a given point (well), along a given line (rivers, streams, etc.), or for a given region (variable surface infiltration from natural precipitation or irrigation). Pumping stresses in each layer of the subregion can be defined as a function of time.

Assumptions and/or Limitations

The following assumptions have been incorporated in the FE3DGW program (source: NRC 1982):

- Darcy's law is valid and hydraulic head gradients are the only significant driving mechanism for fluid flow.
- The porosity and hydraulic conductivity are constant with time.
- Gradients of fluid density, viscosity, and temperature do not affect the velocity distribution.
- The storage term is a function of the compressibility of the fluid and porous medium only.
- The medium is fully saturated.
- Hydraulic conductivity principal axes are aligned parallel to the coordinate axes.
- Verification and/or validation studies. The FE3DGW model has been verified using the radial confined and leaky aquifer solutions documented in Theis (1935) and Hantush (1960), respectively, and the two-dimensional model PATHS (Nelson and Schur 1980). Field

applications of FE3DGW include groundwater studies of Long Island, New York (Gupta and Pinder 1978) and Sutter Basin, California (Gupta and Tanji 1976).

Programming Considerations

FE3DGW is written in FORTRAN IV and operates on PDP-11/45 computers. Auxiliary programs are included that plot grid values, contour maps, and three-dimensional charts of both the input data used in the simulation and the resulting output.

Current Contact

Charles R. Cole, K6-77
Battelle, Pacific Northwest Laboratories
P.O. Box 999
Richland,WA 99352
509-376-8451

Source

Gupta, S. K., C. R. Cole, and F. W. Bond. 1979. Finite Element Three-Dimensional Ground-Water (FE3DGW) Flow Model Formulation. Program Listings and User's Manual. PNL-2939, Pacific Northwest Laboratory, Richland, Washington.

5.4 GENII

The Hanford Environmental Dose System (Generation II or GENII) includes the second generation of Hanford environmental dosimetry computer codes. This coupled system of computer codes was developed as part of the Hanford Environmental Dosimetry Upgrade Project and incorporates the internal dosimetry models recommended by the International Commission on Radiological Protection (ICRP) (ICRP 1977, 1979) in updated versions of the environmental pathway analysis models used at Hanford.

The GENII system provides a technically peer-reviewed, documented set of programs for calculating radiation doses from radionuclides released to the environment. The seven linked computer codes and associated data libraries contained in GENII perform essentially the same calculations as found in previous radiation dosimetry programs. The core system of GENII can calculate annual doses, dose commitments, or accumulated doses from acute or chronic releases of radioactive materials to air or water. These calculations were previously supplied by the computer codes KRONIC (Strenge and Watson 1973), SUBDOSA (Strenge et al. 1975), DACRIN (Houston et al. 1974; Strenge 1975), ARRRG and FOOD (Napier et al. 1980b), and PABLM (Napier et al. 1980a). GENII also can calculate annual doses, dose commitments, and accumulated doses from initial contamination of soil or surfaces, thus incorporating capabilities from PABLM and ONSITE/MAXI (Kennedy et al. 1986, 1987 Napier et al. 1984). A limited biotic transport capability is included that can simulate the results of BIOPORT/MAXI (McKenzie et al. 1985). GENII contains a modified version of the shielding code ISOSHLD (Engle et al. 1966; Simmons et al. 1967) that creates factors relating sources with various geometries to dose rates. An essentially unchanged version of DITTY (Napier et al. 1986) has been added for predicting doses from waste management operations to the public during periods as long as 10,000 years.

The documentation for GENII consists of three volumes. Volume 1 describes the theoretical considerations of the system, including the conceptual diagrams, mathematical representations of the solutions, and descriptions of solution techniques. Volume 2 is a User's Manual providing code structure, user's instructions, required system configurations, and

QA-related topics. Volume 3 is a code Maintenance Manual for the serious user, including code logic diagrams, a global dictionary, worksheets and example hand calculations, and listings of the code and its associated data libraries.

<u>Assumptions and/or Limitations</u>

The assumptions and/or limitations that apply to the GENII system are nearly identical to those described for the first generation dosimetry codes that have been incorporated in this package. Readers are therefore referred to the detailed descriptions of these codes listed separately in Appendix B.

GENII was developed under a QA plan based on the ANSI standard NQA-1 and has undergone two external peer reviews. All steps of the code development have been thoroughly documented and tested. Worksheets and example hand calculations have been provided in the documentation for GENII.

<u>Programming Considerations</u>

GENII is written in FORTRAN and operates on IBM AT, PS/2, and compatible computers (requires a math coprocessor).

<u>Current Contacts</u>

Bruce Napier, K3-54
Battelle, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-375-3896

Rebecca A. Peloquin, K3-54
Battelle, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-375-3916

<u>Source</u>

Napier, B. A., R. A. Peloquin, D. L. Strenge, and J. V. Ramsdell. 1988. <u>Hanford Environmental Dosimetry Upgrade Project. GENII - The Hanford Environmental Radiation Dosimetry Software System (3 vols.)</u>. PNL-6584, Pacific Northwest Laboratory, Richland, Washington.

5.5 ISC

The ISC (Industrial Source Complex) Dispersion Model updates various EPA dispersion algorithms and combines them in a comprehensive program for assessing air quality impacts associated with chemical emissions from an industrial source complex. The ISC model was developed to handle dispersion analysis problems involving complicated source configurations and special atmospheric effects requiring consideration of factors such as fugitive emissions, aerodynamic wake effects, gravitational settling, and dry deposition.

The program consists of two models: the ISC Long-Term (ISCLT) model and the ISC Short-Term (ISCST) model. The ISCST model, an updated version of the EPA Single Source (CRSTER) Model (EPA 1977), uses sequential hourly meteorological data to calculate the average concentration or total dry deposition of emissions for time periods of 1, 2, 3, 4, 6, 8, 12, and 24 hours. Calculation of annual concentration or deposition values is possible if sequential hourly meteorological data are available for an entire year. The ISCLT model is a sector-averaged model that uses statistical wind summaries (tabulation of the joint frequency of occurrence of wind-speed and wind-direction categories, classified according to Pasquill stability categories) to calculate seasonal (quarterly) and/or annual ground-level concentration or deposition values. The ISCLT model extends and combines basic features of the Air Quality Display Model (AQDM) and the Climatological Dispersion Model (CDM). Both the ISCST and ISCLT models can use either a polar- or Cartesian-coordinate receptor grid.

Assumptions and/or Limitation

The following assumptions and/or limitations apply to the ISC program:

- Users are given the option of either entering site- or source-specific data or of using preselected default values for various parameters including wind-profile exponents, vertical potential temperature gradients, plume entrainment coefficients, time-dependent exponential decay of pollutants, stack-tip downwash, building wake effects, plume rise calculated as a function of downwind distance, and dry deposition.

Programming Considerations

The ISC program is written in FORTRAN IV and runs on UNIVAC 1110 computers. However, the programs are designed to operate on most medium- to large-scale computers with minimal or no modifications. Program modifications required for operation on computers other than UNIVAC 1100 series computers are given in the User's Guide (EPA 1987).

Current Contact

Donald L. Hadley, K5-20
Batelle, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-375-3708

Sources

U.S. Environmental Protection Agency. 1977. User's Manual for Single Source (CRSTER) Model. EPA-450/2-77-013, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

U.S. Environmental Protection Agency. 1979. Industrial Source Complex (ISC) Dispersion Model User's Guide, Vol. I and II. 450/4-79-030 and 450/4-79-031, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

U.S. Environmental Protection Agency. 1987. Industrial Source Complex (ISC) Dispersion Model User's Guide, Second Edition (revised), Vol. I and II. EPA-450/4-88-002a and EPA-450/4-88-0026, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

5.6 MMT

MMT (Multicomponent Mass Transfer) was developed to predict the movement of radiocontaminants in the saturated and unsaturated sediments of the Hanford Site. Water movement patterns produced by either an unsaturated or saturated flow model are coupled with dispersion and soil-waste reaction submodels to predict the spatiotemporal distribution and transport of radioactive contaminants.

MMT has undergone several developmental changes, and documentation exists for both one-dimensional (Washburn et al. 1980) and two-dimensional (Ahlstrom et al. 1977) versions of the program. An analog referred to as the Discrete-Parcel-Random-Walk (DPRW) algorithm is used to simulate mass transport processes in the most recent generation of the program.

MMT is a direct simulation type of transport analog adapted from an earlier thermal transport model (Eliason and Foote 1972). The advantages of using a direct simulation model versus the "model equation" approach include 1) the direct simulation model is always mass conservative, 2) there is no cumulative numerical dispersion, 3) the direct simulation model has greater numerical stability, and 4) it facilitates the handling of multicomponent systems. A principal advantage of MMT over other flow network codes is its ability to model nuclides that are present as more than one chemical species.

Both graphic and printed output of contaminant release rates are provided by MMT. In addition, output from the one-dimensional version of MMT can be interfaced with programs that calculate dose to humans.

Assumptions and/or Limitations

The documentation for MMT (Ahlstrom et al. 1977) contains a thorough discussion of the critical assumptions and limitations of the various program components. A condensed list of the more important assumptions and/or limitations is provided here.

- When velocity distributions are calculated before transport simulation, it is assumed that the advection patterns are not dependent on the chemical composition or temperature of the solution (i.e., momentum, mass, and energy transport processes are decoupled). This assumption is only valid for systems that are nearly isothermal and contain relatively low concentrations of contaminants.

- It is assumed that the relative mass flux can be adequately described by expressions having the form of Fick's First Law.

- MMT uses an engineering-oriented approach to model mass transport that views chemical solutions as systems containing a finite number of discrete particles of matter. Because of computational restrictions, contaminants must be represented by a relatively small number of discrete particles.

- Radionuclide decay chains can only be treated by the one-dimensional version of MMT.

- Verification and/or validation studies. MMT has been compared with analytic results obtained from GETOUT. The two-dimensional version of MMT has been used to model the migration of tritium at the Hanford Site. An error and sensitivity analysis for MMT is documented in Ahlstrom et al. (1977).

Programming Considerations

MMT is written in FLECS, a high-order language that compiles into FORTRAN IV and operates on DEC PDP 11/70 and 11/45 computers.

Current Contact

Charles R. Cole
Battelle, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-376-8451

Sources

Ahlstrom, S. W., H. P. Foote, R. C. Arnett, C. R. Cole, and R. J. Serne. 1977. Multicomponent Mass Transport Model: Theory and Numerical Implementation (Discrete-Parcel-Random-Walk Version). BNWL-2127, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Eliason, J. R., and H. P. Foote. 1972. Long Beach Generating Station Thermal Transport Modeling Study. Prepared for the Southern California Edison Company by Battelle, Pacific Northwest Laboratories, Richland, Washington.

Washburn, J. F., F. E. Kaszeta, C. S. Simmons, and C. R. Cole. 1980. Multicomponent Mass Transport Model: A Model for Simulating Migration of Radionuclides in Groundwater. PNL-3179, Pacific Northwest Laboratory, Richland, Washington.

5.7 ORIGEN2

ORIGEN2 is a versatile point depletion and decay program for use in simulating nuclear fuel cycles and calculating the nuclide compositions of various nuclear materials. The original ORIGEN program (Bell 1973) was designed for use in generating spent fuel and waste characteristics (composition, thermal power, etc.) that would form the basis for the study and design of fuel reprocessing plants, spent fuel shipping casks, waste treatment and disposal facilities, and waste shipping casks. Enhancements appearing in ORIGEN2 include 1) substantial changes to the input/output and control features of the computer program, 2) the inclusion of relatively sophisticated reactor physics calculations for different reactor/fuel combinations, and 3) calculation of spectrum-weighted cross sections and fission product yields for approximately 230 nuclides.

ORIGEN2 uses the matrix exponential method to solve a large system of coupled, linear, first-order ordinary differential equations with constant coefficients. The matrix exponential technique was developed to solve a nonhomogeneous system of equations, which makes it possible for ORIGEN2 to be used in calculating the accumulation of radioactivity in processing plants, in waste disposal operations, and in the environment.

Assumptions and/or Limitations

The following assumptions and/or limitations apply to the ORIGEN2 program:

- Nuclear transmutation and decay are represented as a simultaneous system of linear, homogeneous, first-order ordinary differential equations with constant coefficients.
- The build-up and depletion of nuclides during irradiation is calculated using zero-dimensional (i.e., point) geometry and quasi-one-group neutron cross sections. This means that ORIGEN2 cannot account for spatial or resonance self-shielding effects or changes in the neutron spectrum other than those initially encoded.
- Elemental chemical toxicity used in ORIGEN2 are from Dawson (1974).

Programming Considerations

ORIGEN2 is written in FORTRAN, and versions are available that run on IBM and CDC-compatible computers. A separate user's manual for ORIGEN2 is documented in Croff (1980a,b). An extensive library of nuclear data (half-lives and decay schemes, neutron absorption cross sections, fission yields, disintegration energies, and multigroup photon release data) is included with the program.

Current Contact

Urban P. Jenquin, K6-42
Battelle, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-376-1110

Sources

Bell, M. J. 1973. ORIGEN-The ORNL Isotope Generation and Depletion Code. ORNL-4628, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Croff, A. G. 1980a. ORIGEN2: A Revised and Updated Version of the ORNL Isotope Generation and Depletion Code. ORNL-5621, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Croff, A. G. 1980b. A User's Manual for the ORIGEN2 Computer Code. ORNL/TM-7175, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Dawson, G. W. 1974. The Chemical Toxicity of Elements. BNWL-1815, Pacific Northwest Laboratory, Richland, Washington.

5.8 PORFLO

PORFLO contains a continuum model for fluid flow, heat transfer, and mass transport, and was written for assessing the postclosure performance of a proposed high-level nuclear waste repository at the Hanford Site. The program is specifically designed to accommodate the layered nature of the flood basalts found at this site.

PORFLO uses a series of parabolic differential equations, coupled through time-varying parameters, to provide numerical solutions to fluid flow, heat transfer, and mass transport problems. The governing equations are derived from the principles of conservation of mass, momentum, and energy in a stationary control volume that is assumed to contain a heterogeneous, anisotropic porous medium.

The numerical method of nodal-point integration is used to discretize the governing equations over a nonuniform net of rectangular elements. Various techniques such as the alternating direction implicit method and Choleski decomposition are used to solve the set of algebraic equations. PORFLO uses either a two-dimensional Cartesian coordinate system or a three-dimensional axisymmetric cylindrical coordinate system. In the coupled mode, the governing equations are solved sequentially starting with the fluid flow equation, followed by the heat transfer equation, and ending with the mass transport equation. An option in the program allows the user to solve the equations either individually or in sets of two.

Assumptions and/or Limitations

The following assumptions have been incorporated in the PORFLO program:

- The porous media and the fluid are continua that are at least piecewise continuous.
- The porous media and the fluid are only slightly compressible so that equations can be derived in a fixed (rather than deforming) coordinate system.
- The fluid velocity is small so that inertia terms are negligible and Darcy's law is applicable.
- Variation of fluid density and viscosity with fluid pressure is negligibly small.

- Variations in the porosity of the porous medium as a result of stress changes have been ignored.
- Heat and mass transport caused by Dufour and Sorret effects, respectively, are negligible.
- Dispersive heat and mass transport can be described by a linear gradient law.
- The porous medium and the fluid are in thermal equilibrium at all times.
- Adsorption and desorption are the only chemical processes considered. It is assumed that they occur at high speed and that equilibrium is attained instantaneously.
- A linear isotherm is assumed to describe the adsorption/desorption process.
- Verification and/or validation studies. PORFLO has been tested by comparing simulation results with 1) analytic solutions, 2) results from independently developed numerical models, such as MAGNUM-2D, and 3) laboratory and field data. A separate verification and benchmarking report for PORFLO is documented in Eyler and Budden (1984).

Programming Considerations

PORFLO Version 5.6 is written in FORTRAN IV and operates on PRIME 240 and 750 computers. A separate User's Guide for PORFLO is documented in Kline et al. (1983). Both three-dimensional (PORFLO3) and Monte Carlo (PORMC-SF) versions of PORFLO have been developed, but documentation for these programs is unavailable at this time. A partially saturated version of PORFLO3 is currently under development.

Current Contacts

John L. Smoot, K6-77
Battelle, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-376-1352

Naill W. Kline, HO-31
Westinghouse Hanford Company
P.O. Box 1970
Richland, WA 99352
509-376-8080

Sources

Eyler, L. L., and M. J. Budden. 1984. Verification and Benchmarking of PORFLO: An Equivalent Porous Continuum Code for Repository Scale Analysis. PNL-5044, Pacific Northwest Laboratory, Richland, Washington.

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5.9 RADTRAN III

RADTRAN III is used to evaluate possible health and economic impacts associated with the transportation of radioactive materials. The program uses a combination of meteorological, demographic, health physics, transportation, packaging, and material factors to analyze risks associated with both normal transport (incident-free) and various user-selected accident scenarios.

The RADTRAN III program consists of seven submodels: 1) a material model that allows users to select basic material parameters including number of curies per package, average total photon energy per disintegration, the rate at which released material is deposited on the ground, cloudshine dose factors, the physical character of the waste, half-life, and measures of the radiotoxicity of the dispersed material; 2) a transportation model that considers accident rates for each transportation mode (truck, van, rail, cargo and passenger air, barge, and ship), traffic patterns (fraction of travel occurring on various road types, through different population zones, and under both rush-hour and normal traffic conditions), and basic shipment information (number of crew per vehicle, handling and storage times, duration and number of stops); 3) an accident severity and package release model that classifies accidents according to severity (i.e., fire; crush, impact, and puncture forces) and defines the respirable fraction (particles <10 μm) of airborne material released from packages; 4) a meteorological dispersion model that describes the diffusion of a cloud of aerosolized debris released during an accident; 5) a population distribution model that describes the distribution and relative densities of people in three population zones (rural, suburban, and urban), and in certain specific areas, such as pedestrian walkways, warehouses, and air terminals; 6) a health effects model that evaluates the radiotoxicity of materials in terms of potential for producing acute fatalities, early morbidities, genetic effects, and latent cancer fatalities; and 7) an economic model that evaluates the economic impacts connected with surveillance, cleanup, evacuation, and long-term land-use denial activities.

The radiological impacts from transportation accidents are expressed according to the level of consequence, probability of occurrence, and level of risk. A risk figure-of-merit is calculated by summing the products of the probability of each specific accident and its associated level of consequence.

Assumptions and/or Limitations

The following assumptions have been incorporated in the RADTRAN III program:

- Dose calculations in the population exposure model assume that the package or shipping cask is a point source of radiation.
- Radioactive materials released from a package during an accident are assumed to be dispersed according to standard Gaussian diffusion models.
- External radiation exposures from ground contamination are calculated using an infinite plane source model (Taylor and Daniel 1982).
- Verification and/or validation studies. Sensitivity analyses have been performed for several applications (i.e., incident-free transportation, vehicular accidents) of the RADTRAN III program and are documented in Madsen et al. (1986).

Programming Considerations

RADTRAN III is written in FORTRAN V and runs on CDC 6600-7600 series and CRAY computers. A separate user's manual (Madsen et al. 1983) documents the various options for generating accident scenarios and provides additional instructions for computer operators.

Current Contact

Philip M. Daling, K6-40
Battelle, Pacific Northwest Laboratories
P.O. Box 999
Richland WA, 99352
509-376-4765

Sources

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5.10 TRANSS

TRANSS contains a simplified groundwater transport model and can be used to estimate the rate of migration of a decaying radionuclide that is subject to sorption governed by a linear isotherm. TRANSS employs simple analytical solutions of the advection-dispersion equation to describe solute movement along a collection of hydrologic streamlines composing a hypothetical streamtube. Local dispersion along a streamtube is treated as a combination of advection and Fickian diffusion, based on an effective dispersion coefficient.

Contaminant release from a source is described in terms of a fraction-remaining curve provided as input information. An option in the program allows for the calculation of a fraction-remaining curve based on four specialized release models: 1) constant release rate, 2) solubility-controlled release, 3) adsorption-controlled release, and 4) diffusion-controlled release from beneath an infiltration barrier.

Assumptions and/or Limitations

The following assumptions have been incorporated in the TRANSS program:

- It is assumed that contaminant transport can be represented by a collection of one-dimensional problems defined by the streamlines of a flow field under steady-state conditions.
- Transverse dispersion within a streamtube is assumed to be negligible.
- Travel times along streamlines must be obtained from a prior groundwater flow simulation.
- TRANSS is not a predictive program. The program is intended to be used as a scoping tool for estimating the relative influence of transport controlling parameters. Moreover, output estimates depend conditionally on the specific groundwater flow field used as input.
- Verification and/or validation studies. TRANSS has been verified for a number of sample problems, including well-documented test cases involving the transport of single radionuclides (Simmons and Cole 1985).

Current Contact

Marcel P. Bergeron, K6-77
Battelle, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-376-8410

Sources

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5.11 UNSAT-H

UNSAT-H contains a hydrologic model for simulating water and heat flow in unsaturated soils and is used primarily for assessing the water and energy dynamics of arid sites under consideration for near-surface waste disposal. The program can be used to predict deep drainage (i.e., recharge) as a function of environmental conditions such as climate, soil type, and vegetation. An additional application includes the simulation of various waste management practices, such as placing surface barriers over waste sites.

UNSAT-H employs a one-dimensional, mechanistic model that simulates the dynamic processes of infiltration, drainage, redistribution, surface evaporation, uptake of water from soil by plants, energy exchange between the soil surface and the overlying atmosphere, and the flow of heat within the soil. The mathematical basis of the model is Richards' equation of water flow, Fourier's law of heat conduction, and Fick's law of diffusion. The basic numerical implementation is patterned after the UNSAT model of Gupta et al. (1978).

UNSAT-H uses a fully implicit, finite-difference method for solving the water and heat transport equations. Plant water uptake is introduced as a sink term at each node and is calculated as a function of root density, water content, and potential evapotranspiration. The simulated soil profile can be homogeneous or layered. The boundary conditions can be controlled as either constant head or flux conditions depending on the specific conditions at a given site.

Features of UNSAT-H Version 2.0 that are improvements over the original UNSAT and earlier versions of UNSAT-H include a cheatgrass transpiration function, additional options for describing soil hydraulic properties, consideration of heat and nonisothermal vapor flow, direct calculation of evaporation, and reduction of mass-balance error.

Output from UNSAT-H consists of the following: 1) hourly or daily summaries of water content, water potential, water and heat fluxes, temperature, and plant water use as a function of depth, and 2) cumulative totals of the water and heat balance components (storage, precipitation, evaporation, transpiration, drainage, net radiation, sensible heat, latent heat).

Assumptions and/or Limitations

The following assumptions have been incorporated in the UNSAT-H program:

- Water and heat flows in one dimension.
- Richard's equation, Fourier's law, and Fick's law are valid.
- Liquid water flow is not induced by temperature gradients.
- Air phase is continuous and at constant pressure.
- Soil hydraulic properties are independent of soil temperature.
- Soil hydraulic properties are unique (i.e., not hysteretic).
- Plant growth, development, and transpiration can be described empirically.
- Precipitation and evaporation are not affected by snow cover and snowmelt.
- Verification and/or validation studies. Successful verification tests of the processes of infiltration, redistribution, and drainage have been performed using UNSAT1D (see Simmons and Cole 1985), a precursor model of UNSAT-H. The UNSAT-H model has been tested using measured field data from the 200-Area closed-bottom lysimeter (Fayer et al. 1986, Appendix B). Fayer and Jones (1990) contains verification tests for the processes of infiltration, redistribution, and drainage and for heat flow. Baca and Magnuson (1990) contains four verification and four benchmark test cases that cover both water and heat flow scenarios in both homogeneous and layered media.

Programming Considerations

UNSAT-H Version 2.0 is written in VAX FORTRAN Version 4.7 and runs under the VAX/VMS Version 4.7 Operating System.

Current Contact

Michael J. Fayer, K6-77
Battelle, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-376-8326

Sources

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Fayer, M. J., and T. L. Jones. 1990. UNSAT-H Version 2.0: Unsaturated Soil Water and Heat Flow Model. PNL-6779, Pacific Northwest Laboratory, Richland, Washington.

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5.12 VTT

The VTT (Variable Thickness Transient) groundwater modeling system is a collection of programs used for assessing the far-field, long-term, post-closure safety of deep geologic nuclear waste repositories. VTT defines the groundwater flow field and provides water flow paths and travel times for multilayer aquifer systems. A Boussinesq approximation method is used to provide a simplified, two-dimensional view of confined, unconfined, or semiconfined groundwater systems.

Three separate versions of the program, each utilizing different solution techniques to solve the same set of equations, have been created to handle specific problems. The VTT version solves the transient form of the system of finite-difference equations using the successive line over-relaxation technique. For transient problems the solution is stable and convergent with sufficient speed to make solution of large matrices practical. The VTTSS3 version utilizes a Newton iteration technique and is primarily used for a system of aquifers in which one is confined and, therefore, the equations are nonlinear. Convergence of this method is quadratic in nature, and for most groundwater problems the solution is reached in four or five iterations. The VTTSSZ version uses a Colesky decomposition method and is used when all the aquifers being simulated are confined.

Assumptions and/or Limitations

VTT is a quasi-three-dimensional code in that it simplifies the solution of three-dimensional flow equations by transforming them into a series of coupled two-dimensional problems. This assumption would not be valid for aquifers with three-dimensional flow fields. Specific assumptions of the Boussinesq flow model used for describing saturated unconfined flow include the following:

- Flow is by an incompressible fluid that saturates a rigid, porous soil matrix.
- Compressibility effects of the fluid and soil matrix can be neglected under conditions of unconfined or free-surface flow; however, they are incorporated into the storage term for confined flow.

- Hydraulic conductivity and effective porosity can be represented by the vertical average values are isotropic but nonhomogeneous throughout the region.

- The free-surface slope and the aquifer bottom slope are both assumed to be slight (<5°).

- Vertical velocities are assumed to be small and therefore can be neglected.

- Coefficient distributions are dependent variables and are assumed continuous over the simulation region.

- Flow in the capillary fringe is neglected.

- Seepage surfaces cannot be handled and are therefore neglected.

- Verification and/or validation studies. Output from VTT has been compared with solutions obtained from both two-dimensional (PATHS, Nelson and Schur 1980) and three-dimensional (FE3DGW, Subsection 5.3) models.

Programming Considerations

VTT is written in FORTRAN IV-PLUS and runs on PDP 11/45 computers.

Current Contact

Mark D. Freshley, K6-96
Batteile, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-376-8315

Source

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APPENDIX A

MODELS WITH NO CURRENT CONTACT

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CHAINT

CHAINT contains a two-dimensional hydrologic model that can be used to analyze radionuclide transport in a fractured porous medium. CHAINT is a deterministic, waste package-scale (very near-field) code that accounts for the physical processes of advection, dispersion, diffusion, retardation, radionuclide chain decay coupling, and mass injection.

CHAINT employs a computational scheme based on a Galerkin finite-element method and block-diagonal frontal solution technique. The program is applicable to problems that can be formulated in two dimensions using rectangular coordinates or axisymmetric radial coordinates. Continuum portions of the medium are modeled with two-dimensional isoparametric elements, and discrete features are modeled with one-dimensional elements that are embedded along the sides of the continuum elements.

Principal input to the program consists of files from a previous MAGNUM-2D (Appendix A) simulation of buoyancy driven fluid flow. Output from CHAINT includes a printed report of contaminant concentrations along with postprocessor graphics files.

Assumptions and/or Limitations

The following assumptions have been incorporated in the CHAINT program:

- The diffusive flux is assumed to be Fickian.
- Radionuclide transport occurs only in fractures.
- Sorption may be represented by equilibrium adsorption.
- The assumptions incorporated in MAGNUM-2D also apply to CHAINT (refer to Appendix A).

Programming Considerations

CHAINT Version 2.1 is written in FORTRAN 77 and operates on PRIME 750 minicomputer networks. Earlier versions were written to run on UNIVAC 1100/44, CRAY 1, and PRIME minicomputers. Transportability of the program has been given a high priority, and most features of the current version are machine independent. A set of support codes and graphics software has been developed and interfaced with the CHAINT code to 1) generate, manipulate, and display the finite-element grid, 2) compute and plot the mass flux across selected boundaries, and 3) plot contours, spatial cross sections, and time histories of concentrations.

Sources

King, I. P., D. B. McLaughlin, W. R. Norton, R. G. Baca, and R. C. Arnett. 1981. Parametric and Sensitivity Analysis of Waste Isolation in a Basalt Medium. RHO-BWI-C-94, Rockwell Hanford Operations, Richland, Washington.

Kline, N. W., R. L. England, and R. G. Baca. 1986. CHAINT Computer Code: User's Guide, RHO-BW-CR-144 P, Rockwell Hanford Operations, Richland, Washington.

MAGNUM-2D

MAGNUM-2D contains a two-dimensional hydrologic model for transient or steady-state analysis of coupled heat transfer and ground-water flow in a fractured porous medium. The program was developed for simulating the thermal and hydraulic conditions in the vicinity of a waste package emplaced in a deep geologic repository. MAGNUM-2D is used to calculate 1) the temperature field surrounding the waste package as a function of the heat generation rate of the nuclear waste and thermal properties of the basalt, and 2) the hydraulic head distribution and associated ground-water flow fields as a function of the temperature gradients and hydraulic properties of the basalt.

The governing equations in MAGNUM-2D consist of a set of coupled, quasi-linear partial differential equations that are solved using a Galerkin finite-element technique. A Newton-Raphson algorithm is embedded in the Galerkin function to formulate the problem in terms of the incremental changes in the dependent variables. Both triangular and quadrilateral finite elements are used to represent the continuum portions of the spatial domain. Line elements may be used to represent flow in discrete conduits or fractures (macroscale discontinuities).

Assumptions and/or Limitations

The following assumptions have been incorporated in the MAGNUM-2D program (Source: U.S. NRC 1982):

- The fractured-porous medium is nondeformable.
- The fluid is slightly compressible.
- Flow is laminar (Darcian).
- Macroscale hydraulic gradients are independent of fracture orientation or geometry.
- The fluid system is single-phase.
- The medium is fully saturated.
- Moisture is stored in both primary and secondary pores.
- Flow in fractures is governed by a nonisothermal version of Darcy's law.

- Flow between primary and secondary pores depends on the difference between primary and secondary heads.

- Heat flux is governed by the convection-diffusion equation.

- Conservation of mass applies separately in the primary and secondary storage systems, but conservation of energy applies in the system as a whole.

- Verification and/or validation studies. The ground-water flow and energy transport components of MAGNUM-2D have been verified against analytic solutions obtained from the SEMTRA program (a forerunner of MAGNUM-2D) for three classes of problems: 1) a simplified flow problem, 2) a thermal dispersion problem, and 3) a coupled heat and fluid flow (non-isothermal) problem.

Programming Considerations

MAGNUM-2D Version 3.1 is written in FORTRAN 77 and operates on PRIME 750 minicomputer networks. Earlier versions of the program were designed to run on UNIVAC 1100/44, CRAY 1, and PRIME computers. Transportability of the program has been given a high priority and most features of the code are machine independent. A set of support codes and graphics software has been developed and interfaced with the MAGNUM-2D program to 1) generate, manipulate, and display the finite element grid, 2) compute and plot pathlines/streamlines and travel times, and 3) plot contours, spatial cross sections, and time histories for temperature and hydraulic head.

Sources

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APPENDIX B

FIRST GENERATION OF HANFORD DOSIMETRY CODES

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ALLDOS

ALLDOS was developed to calculate radiation doses from postulated releases of aged radioactive wastes. The program is used primarily as a "report generator" to calculate maximum individual and population dose tables from release inventories and dose conversion factors. ALLDOS considers both chronic and acute releases of radiation.

ALLDOS uses three release terms in describing exposure scenarios: 1) airborne release for external and inhalation exposure, 2) airborne release for terrestrial pathways (ingestion/external), and 3) waterborne releases for terrestrial and aquatic pathways (ingestion/external). Separate release terms are defined for each release pathway and an optional procedure is provided to generate release terms from a basic radionuclide inventory. ALLDOS relies heavily on the use of precalculated dose conversion factors to describe terrestrial pathways and radiation dosimetry. Dose conversion factors defined for each release pathway are used to generate dose commitments to a maximum individual and the population in the region of the release site.

Output from ALLDOS consists of the dose contribution from each release pathway plus the total dose to selected organs. The dose contribution fraction by radionuclide for each organ is also reported as an option.

Assumptions and/or Limitations

The following assumptions have been incorporated in the ALLDOS program:

- Inhalation dose conversion factors are obtained from the program DACRIN (Appendix B). Calculations in DACRIN are based on the respiratory tract model adopted by the International Commission on Radiological Protection (ICRP) Task Group on Lung Dynamics (ICRP 1966; ICRP 1972).
- ALLDOS uses the gastrointestinal tract and organ retention models documented in ICRP Publication 2 (ICRP 1959).
- Dose conversion factors for terrestrial and aquatic pathways are obtained from the program PABLM (Appendix B). Dose conversion factors are based on site-specific assumptions concerning various demographic and lifestyle (i.e., dietary and recreational habits) features of the exposed population.

- A tissue depth of 5 cm is assumed in calculating external doses to blood-forming organs, and this approximation is used to determine the dose contributions to all organs.

- Radioactive decay in transit from the release point to the location of exposure is ignored because ALLDOS calculates doses for aged radioactive wastes containing nuclides with relatively long half-lives.

Programming Considerations

ALLDOS is written in ASCII FORTRAN and versions are available that operate on IBM PC and VAX 11/780 computers.

Current Contact

Dennis Strenge, K6-96
Battelle, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-376-2610

Source

Strenge, D. L., B. A. Napier, R. A. Peloquin, and M. G. Zimmerman. 1980. ALLDOS-A Computer Program for Calculation of Radiation Doses from Airborne and Waterborne Releases. PNL-3524, Pacific Northwest Laboratory, Richland, Washington.

ARRRG

ARRRG (Aqueous Reactor Release Result Generator) and its companion program FOOD (Appendix B) provide rapid estimates of the radiation dose and dose commitment to man resulting from radioactive materials released to the environment. ARRRG was written to address aquatic exposure routes, and can calculate doses for five ingestion pathways (fish, mollusks, crustaceans, plants, and drinking water) and three external pathways (swimming, boating, and shoreline exposure).

The fundamental equations used in the ARRRG program are documented in Soldat et al. (1974). The program calculates dose for either a maximally exposed individual or for a population. ARRRG calculates 1-year doses and dose commitments for any one or a combination of radionuclides for which sufficient biological data are available. As many as five of 23 possible organs and tissues, and mixtures of up to 100 radionuclides, may be selected for any one exposure scenario. Calculations are based on chronic exposures, although equations are included that can treat acute (one-time) exposures.

The output from ARRRG consists of 1) radiation dose and dose commitment summaries for all chosen organs listed by exposure pathway and by radionuclide, 2) complete listing of dose contributions by radionuclide for each pathway (optional), and 3) radionuclide concentrations in all ingested plant and animal material.

Assumptions and/or Limitations

The following assumptions have been incorporated in the ARRRG program:

- The equations for calculating internal dose and dose commitment are derived from those given by the ICRP for body burdens and Maximum Permissible Concentration (MPC) of each nuclide (ICRP 1959). Metabolic parameters for the Reference Man (ICRP 1975) are used.

- Usage parameters (i.e., duration of exposure to external sources of radiation and intake rates of ingested food and water) for the average adult are assumed in population dose calculations.

- Radionuclide concentrations in the sediments of a river or lake downstream from a discharge point are calculated by assuming that 1) there is a constant water concentration for each year of the release, 2) the deposition rate to the sediment is dependent only on water concentration and, 3) removal from the sediments is only by radioactive decay.

- The radiation dose to individuals swimming in contaminated water is calculated by assuming that the body of contaminated water is large enough to be considered an "infinite medium" relative to the range of emitted radiations.
- An "infinite" flat-plane source model is used to calculate radiation doses from contaminated shorelines. A factor of two is included to account for surface roughness. Shoreline calculations include a modifying factor to compensate for finite extent.
- Persons boating on contaminated water are assumed to be exposed to a dose rate half that of swimmers.

Programming Considerations

ARRRG is written in ASCII FORTRAN and runs on UNIVAC 1100/44 computers. Older versions of the program written in Basic are no longer maintained at PNL.

Current Contact

Bruce Napier, K3-54
Battelle, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-375-3896

Sources

Napier, B. A., R. L. Roswell, W. E. Kennedy, Jr., and D. L. Strenge. 1980. ARRRG and FOOD-Computer Programs for Calculating Radiation Dose to Man from Radionuclides in the Environment. PNL-3180, Pacific Northwest Laboratory, Richland, Washington.

Soldat, J. K., N. M. Robinson, and D. A. Baker. 1974. Models and Computer Codes for Evaluating Environmental Radiation Doses. BNWL-1754, Pacific Northwest Laboratory, Richland, Washington.

BIOPORT/MAXI1

BIOPORT/MAXI1 is a collection of computer programs designed to estimate the potential radiation dose to man resulting from biotic transport processes at low-level nuclear waste disposal sites. Dose to man is calculated for ingestion of agricultural crops grown in contaminated soil, inhalation of resuspended radionuclides, and direct exposure to penetrating radiation from soil. In addition to biotic transport, models are included for erosion of soil from the burial site cover and waste package decomposition.

Five programs are contained within the BIOPORT/MAXI1 package: CREATE, an interactive program that allows an end-user to create and evaluate biotic transport scenarios; BIOPORT, which simulates the redistribution of radionuclides by plant and animal processes following intrusion into buried waste and, at specified years during the simulation, calculates soil concentrations of radionuclides; MAXI1, which uses these nuclide concentrations and a standard maximally exposed individual scenario to calculate the maximum annual dose to the exposed individual from the various pathways; and MAXI2 and MAXI3, which generate intermediate dose conversion factors for food and aquatic pathways, and allow experienced users complete access to MAXI1 capabilities.

Assumptions and/or Limitations

The exposure scenarios used in BIOPORT/MAXI1 are based on user-created "reference environments" that define the agricultural and water-usage practices for a particular geographic area and the general lifestyle (i.e., dietary and recreational habits) characteristics of a hypothetical intruder/resident. Users are given the option of either running the default scenarios contained within the program or entering their own baseline data to generate unique scenarios for specific applications. The following assumptions have been incorporated in the BIOPORT/MAXI1 program:

- A maximally exposed individual scenario is assumed throughout the program. The largest of the annual organ doses calculated to occur during a 50-year period of continuing exposure is used in determining the maximum annual radiation dose.

- Intrusion and active physical transport are assumed to be the dominant biotic transport mechanisms; transport enhancement and secondary transport are not considered.

Programming Considerations

BIOPORT/MAXI1 is written in ANSI FORTRAN-77 and was developed initially to run on VAX 11/780 computers. McKenzie et al. (1985) describes changes to the program that are required for operation on CDC 6600-7600 series computers. A database of dose conversion factors (external, soil and leaf mechanism, and inhalation dose conversion factors) and radiological decay information is included with the computer software. Inhalation dose conversion factors are calculated using DACRIN (Appendix B). External dose conversion factors for various waste disposal geometries are calculated using the ISOSHLD (Appendix B) shielding program.

Current Contact

Bruce Napier, K3-54
Battelle, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-375-3896

Sources

McKenzie, D. H., L. L. Cadwell, L. E. Eberhardt, W. E. Kennedy, Jr., R. A. Peloquin, and M. A. Simmons. 1982. Relevance of Biotic Pathways to the Long-Term Regulation of Nuclear Waste Disposal, Topical Report on Reference Western Arid Low-Level Sites. NUREG/CR-2675, Vol. 2, U.S. Nuclear Regulatory Commission, Washington, D.C.

McKenzie, D. H., L. L. Cadwell, K. A. Gano, W. E. Kennedy, Jr., B. A. Napier, R. A. Peloquin, L. A. Prohammer, and M. A. Simmons. 1985. Relevance of Biotic Pathways to the Long-Term Regulation of Nuclear Waste Disposal. Estimation of Radiation Dose to Man Resulting from Biotic Transport: The BIOPORT/MAXI1 Software Package. NUREG/CR-2675, Vol. 5, (PNL-4241), U.S. Nuclear Regulatory Commission, Washington, D.C.

DACRIN

DACRIN is used to generate rapid estimates of the radiation dose to the human respiratory tract and other organs from the inhalation of radioactive aerosols. The program performs dose calculations for up to 22 organs and tissues (maximum of 10 organs/tissues per run). Organ doses are calculated based on the quantity of radionuclide inhaled or, if air dispersion and other supplemental data are provided, for the quantity released to the atmosphere.

DACRIN is based on the respiratory tract model adopted by the ICRP Task Group on Lung Dynamics (ICRP 1966, 1972) and a simple exponential model that calculates radionuclide retention for selected organs and tissues. Mathematical models describing atmospheric dispersion have been included for evaluating doses resulting from either accidental or chronic atmospheric releases of radionuclides.

Output from DACRIN consists of the effective radiation dose to all organs or tissues of interest at selected time intervals for each radionuclide inhaled.

Assumptions and/or Limitations

The following assumptions have been incorporated in the DACRIN program:

- The lung model simplifies calculations of radionuclide deposition and clearance by dividing the respiratory tract into three regions: the nasopharyngeal, tracheobronchial, and pulmonary. Each region is further subdivided into two or more subcompartments, each representing the fraction of material (f_k) initially in a compartment that is subject to a particular clearance process. Clearance half-times and values of f_k for each clearance process and for the three solubility classes of aerosols used in the code are taken from ICRP (1972).

- A constant fraction of the material clearing from the respiratory tract through the GI tract is assumed to be taken up by the blood. A constant fraction of material from the blood is assumed to enter each organ or tissue, and subsequent clearance from the organ or tissue is assumed to occur at a constant rate.

- The bivariate-normal distribution model is used in calculating radionuclide concentrations in air at specified distances from the source.

- The organ dose from daughter nuclides is computed indirectly by utilizing weighted values of the effective energy emitted by the daughter nuclides in the chain.

Programming Considerations

DACRIN is written in FORTRAN-77 and runs on VAX 11/780 computers.

Current Contact

Dennis Strenge, K6-96
Battelle, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-376-2610

Sources

Houston, J. R., D. L. Strenge, and E. C. Watson. 1974. DACRIN-A Computer Program for Calculating Organ Dose from Acute or Chronic Radionuclide Inhalation. BNWL-B-389, Pacific Northwest Laboratory, Richland, Washington.

Strenge, D. L. 1975. DACRIN-Modification for Gastrointestinal Tract Dose. BNWL-B-399, Supplement 1. Pacific Northwest Laboratory, Richland, Washington.

DITTY

DITTY (Dose Integrated over Ten Thousand Years) is used to calculate the collective radiation dose to man from long-term nuclear releases to the environment from any source. DITTY estimates the time integral of collective dose over a 10,000-year period for time-variant radionuclide releases to surface waters, wells, or the atmosphere. Doses are calculated for all contributing pathways of exposure, including external exposure, inhalation, and ingestion of contaminated water and foods.

Atmospheric dispersion calculations provide estimates of ground-level air concentrations of radionuclides as a function of distance and direction from the release location. Dispersion factors relating downwind air concentrations to release rates may be entered by the user or calculated by the program. In the latter case, users must supply meteorological data in the form of joint frequency of occurrence of windspeed, wind direction, and atmospheric stability.

For any specified 10,000-year interval, DITTY calculates the average release for each of 143 successive 70-year periods (human lifetimes). The activity present for each 70-year period is calculated as the sum of the material released during that period (uniformly released over 70 years) plus the residual material in the environment from releases in previous periods.

Assumptions and/or Limitations

The following assumptions have been incorporated in the DITTY program:

- A straight-line crosswind-averaged Gaussian plume model is used to provide estimates of ground-level air concentrations of released radioactivity as a function of distance and direction from the release location.

- The calculation of dispersion factors (crosswind-integrated normalized air concentrations) assumes that the joint frequency data describe the directional dependence of downwind transport, and that transport is uniform across each sector and in a straight line from the release point to the location of interest.

- Radionuclide release-rate data are interpolated and integrated to give the total averaged activity for each 70-year period.

- The effect of climatic change on calculations of population exposure is not considered.

- A constant factor (10^{-9} m^{-1}) is assumed in calculating radionuclide activity from resuspended soil. Downwind transport of resuspended activity is not considered.

- A constant sediment deposition factor (25300 $L/m^2/yr$) is assumed based on historical measurements of radionuclides in water and sediment samples from the Columbia River.

- The concentrations of ^3H and ^{14}C in the carbon and hydrogen of environmental media (soil, plants, and animal products) are assumed to have the same specific activity as in the contaminating medium (air or water). The fractional content of hydrogen or carbon in a plant or animal product is then used to compute the concentration of ^3H or ^{14}C in the food product under consideration. It is assumed that plants obtain all their carbon from irrigation water and that animals obtain all their carbon from the ingestion of plants.

Programming Considerations

DITTY is written in FORTRAN-77 and versions are available that run on either VAX 780 or IBM Personal Computers.

Current Contact

Bruce Napier, K3-54
Battelle, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-375-3896

Source

Napier, B. A., R. A. Peloquin, and D. L. Strenge. 1986. DITTY-A Computer Program for Calculating Population Dose Integrated over Ten Thousand Years. PNL-4456, Pacific Northwest Laboratory, Richland, Washington.

FOOD

FOOD and its companion program ARRRG (Appendix B) provide rapid estimates of the radiation dose and dose commitment to man resulting from radioactive materials released to the environment. FOOD was written to address terrestrial exposure pathways and can compute doses from external exposure and for up to 14 crop or animal product pathways. Radiation doses may be calculated from deposition on farm or garden soil and crops during either an atmospheric or water release of radionuclides. Deposition may be either directly from the air or from irrigation water. The type and amounts of crops grown around the point of release determine which pathways are activated.

The fundamental equations used in the FOOD program are documented in Baker et al. (1976) and Brenchly et al. (1977). The program permits dose calculations for either a maximally exposed individual or for a population. FOOD calculates 1-year dose and dose commitments from any one or combination of radionuclides for which sufficient biological data are available. As many as five of 23 possible organs and/or tissues, and mixtures of up to 100 radionuclides, may be selected for any one exposure scenario.

The output from FOOD consists of 1) radiation dose and dose commitment summaries to all chosen organs listed by exposure pathway and by radionuclide, 2) complete listing of dose contributions by radionuclide for each pathway (optional), and 3) radionuclide concentrations in all ingested plant and animal material.

Assumptions and/or Limitations

The following assumptions have been incorporated in the FOOD program:

- The equations for calculating internal dose and dose commitment are derived from those given by the ICRP for body burdens and MPC of each radionuclide (ICRP 1959). Metabolic parameters for the Reference Man (ICRP 1975) are used.

- Usage parameters (i.e., duration of exposure to external sources of radiation and intake rates of ingested food and water) for the average adult are assumed in population dose calculations.

- The radiation dose from external exposure to contaminated farm fields is calculated assuming an "infinite" flat-plane source model. A factor of two has been included to account for self-shielding by surface roughness.

- Airborne radionuclides are deposited onto plant foliage and soil assuming a constant deposition velocity. In cases involving irrigation, sprinkler irrigation is assumed if site-specific data are lacking. This results in a higher radionuclide concentration in plants (and in the animals consuming them) than for trickle or surface irrigation systems. An option in the program (setting the foliar retention factor to zero) allows for the simulation of surface irrigation systems.

- The concentrations of ^{3}H and ^{14}C in the carbon and hydrogen of environmental media (soil, plants, and animal products) are assumed to have the same specific activity as in the contaminating medium (air or water). The fractional content of hydrogen or carbon in a plant or animal product is then used to compute the concentration of ^{3}H or ^{14}C in the food product under consideration. It is assumed that plants obtain all their carbon from irrigation water and that animals obtain all their carbon from the ingestion of plants.

- Verification and/or validation studies. A sensitivity analysis of the FOOD model is documented in Zach (1980).

Programming Considerations

FOOD is written in ASCII FORTRAN and runs on UNIVAC 1100/44 computers. Older versions of the program written in Basic are no longer maintained by PNL.

Current Contact

Bruce Napier, K3-54
Battelle, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-375-3896

Sources

Baker, D. A., G. R. Hoenes, and J. K. Soldat. 1976. FOOD-An Interactive Code to Calculate Internal Radiation Doses from Contaminated Food Products. BNWL-5523, Pacific Northwest Laboratory, Richland, Washington.

Brenchly, D. L., J. K. Soldat, J. A. McNeese, and E. C. Watson. 1977. Environmental Assessment Methodology for the Nuclear Fuel Cycle. BNWL-2219, Pacific Northwest Laboratory, Richland, Washington.

Napier, B. A., R. L. Roswell, W. E. Kennedy, Jr., and D. L. Strenge. 1980. ARRRG and FOOD-Computer Programs for Calculating Radiation Dose to Man from Radionuclides in the Environment. PNL-3180, Pacific Northwest Laboratory, Richland, Washington.

Zach, R. 1980. Sensitivity Analysis of the Terrestrial Food Chain Model FOOD III. AECL-6794, Whiteshell Nuclear Research Establishment, Pinawa, Manitoba.

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ISOSHLD

ISOSHLD performs gamma ray shielding calculations for isotope sources in a wide variety of source and shielding configurations. Attenuation calculations are performed by point kernel integration. For most geometries this is accomplished by a Simpson's rule integration. Source strength in uniform or exponential distribution may be calculated by the linked fission-product inventory code RIBD (Radio-Isotope Build-up and Decay) or by other options as desired. Build-up factors are calculated by the code based on the number of mean free paths of material between the source and detector points, the effective atomic number of a particular shield region, and the point isotropic NDA build-up, available as Taylor coefficients in the effective atomic number range of 4-82.

Isotopic decay, material attenuation, build-up factors, and other required basic data have been compiled in external libraries that are linked to the program. Users supply data describing the geometry and material composition of the source and the geometry and material of the shield. Optional modes of data entry are available for solving special problems. A supplement to the original program (Simmons et al. 1967) allows the calculation of dose rates from shielded Bremsstrahlung sources. An updated photon library (Mansius 1969) containing 499 isotopes has also been added to the original program.

Assumptions and/or Limitations

The following assumptions or limitations apply to the ISOSHLD program:

- Complex geometries are approximated by combinations of simple geometric shapes.
- Errors may arise when dealing with isotopes or isotopic mixtures with energy yields less than 0.15 MeV or greater than 3.0 MeV.
- ISOSHLD does not contain a neutron attenuation routine.
- Gamma decay schemes have not been measured for all of the isotopes in the program library. Approximately 25% of the 499 isotopes in the library lack either gamma energy or both gamma energy and photon probability data. It is expected that additions will be made to the library as data become available.

Sources

Engel, R. L., J. Greenborg, and M. M. Hendrickson. 1966. ISOSHLD-A Computer Code for General Purpose Isotope Shielding Analysis. BNWL-236, Pacific Northwest Laboratory, Richland, Washington.

Mansius, C. A. 1969. A Revised Photon Probability Library for Use with ISOSHLD III. BNWL-236, Supplement 2, Pacific Northwest Laboratory, Richland, Washington.

Simmons, G. L., J. J. Regimbal, J. Greenborg, E. L. Kelley, Jr., and H. H. Van Tuyl. 1967. ISOSHLD II-Code Revision to Include Calculation of Dose Rate from Shielded Bremsstrahlung Sources. BNWL-236, Supplement 1, Pacific Northwest Laboratory, Richland, Washington.

KRONIC

KRONIC calculates average annual external beta and gamma doses from chronic atmospheric releases of radionuclides. External total-body tissue dose is calculated as a function of 1) gamma and beta particles emitted from the radionuclides present, 2) physical properties describing interactions of gamma and beta particles with air and tissue, 3) the time dependence of fission product concentration, and 4) meteorological conditions at a particular site.

Atmospheric dispersion effects are estimated using data on joint frequency of occurrence of wind speed, wind direction, and stability for a particular site. Each sector is considered to be a plume for which the centerline ground-level dose is calculated for specified downwind distances. Beta dose contributions are calculated using a semi-infinite cloud model. The gamma dose contribution is determined using precalculated factors representing a space integration over the plume volume. An auxiliary program is available with KRONIC for evaluating the plume integrals.

Output from KRONIC consists of a table of annual dose rates reported as a function of direction and distance from the release point.

Assumptions and/or Limitations

The following assumptions are made in calculating radionuclide concentrations in plumes:

- Diffusion along the direction of cloud travel is ignored.
- Vertical cross-wind concentration is normally distributed and the standard deviation is a function of atmospheric stability and distance from the release point. In some dispersion models, this standard deviation is wind-speed dependent.
- The dose receptor is at ground level.
- Cloud depletion by fallout, washout, and rainout can be described by a factor dependent on the distance of travel and is independent of travel time and displacement from the centerline.
- The contribution to dose from radionuclides at distances greater than ± 800 m (from the exposure location) in the direction of cloud travel are ignored.

- A radioactive decay factor is calculated for each radionuclide based on travel time to the exposure point.

<u>Programming Considerations</u>

KRONIC is written in FORTRAN IV and runs on UNIVAC 1108 computers.

<u>Current Contact</u>

Dennis Strenge, K6-96
Batte1le, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-376-2610

<u>Source</u>

Strenge, D. L., and E. C. Watson. 1973. <u>KRONIC-A Computer Program for Calculating Annual Average External Doses from Chronic Atmospheric Releases of Radionuclides</u>. BNWL-B-264, Pacific Northwest Laboratory, Richland, Washington.

ONSITE/MAXI1

The ONSITE/MAXI1 program was originally developed for use by the U.S. Nuclear Regulatory Commission (NRC) Waste Management staff in conducting human intrusion, dose-pathway analyses for onsite burial of low-activity radioactive wastes. The program activates specific human intrusion scenarios that consider various potential combinations of direct exposure to penetrating radiation, inhalation of airborne radionuclides, ingestion of agricultural products raised in contaminated soil, and ingestion of radionuclides in drinking water.

The VAX and CDC versions of the ONSITE/MAXI1 software package contain four computer codes. ONSITE is an interactive user interface that allows the end-user to create and use the radiation exposure scenarios. MAXI1 uses the scenario information to calculate the maximum annual dose to the exposed individual from selected pathways. Doses from inhalation of airborne radionuclides are estimated using dose conversion factors from the program DACRIN (Appendix B). MAXI2 generates intermediate dose conversion factors for terrestrial food pathways (deposition on farm or garden soil and crops) and calculates external dose rate factors for exposure to soil surface contamination. MAXI3 calculates the data files containing intermediate dose conversion factors for drinking-water and aquatic food pathways. In the personal computer version of ONSITE/MAXI1, MAXI2 and MAXI3 have been incorporated into the program rather than being included as separate modules.

Assumptions and/or Limitations

The exposure scenarios used in ONSITE/MAXI1 are based on user-created "reference environments" that define the agricultural and water-usage practices for a particular geographic area and the general lifestyle (i.e., dietary and recreational habits) characteristics of a hypothetical intruder/ resident. Users are given the option of either running default scenarios contained within the program, or entering their own baseline data to generate unique scenarios for specific applications. The following general assumptions and/or limitations apply to the ONSITE/MAXI1 program:

- Dose calculations for external exposure assume that radioactive wastes are located on the surface of the ground, buried at 0.5- and 1.0-m depths, or stored in a room-type structure.

- The personal computer (IBM PC/XT/AT) version of ONSITE/MAXI1 uses radiation dose factors obtained from ICRP Publication 30 (ICRP 1979-1982). The VAX 11/780 and CDC 6600-7600 versions use dose factors from ICRP Publication 2 (ICRP 1959).

- Inhalation dose calculations in the VAX and CDC versions use conversion factors derived from ICRP Publication 2 and the Task Group Lung Model (ICRP 1966) contained in DACRIN (Appendix B). Additional metabolic data for the inhalation calculations are obtained from ICRP Publication 19 (ICRP 1972).

- Dose calculations for inhalation and ingestion exposures use default parameters from Regulatory Guide 1.109 (NRC 1977) to define the reference environment (VAX and CDC versions only).

- The external dose conversion factors for various waste disposal geometries and densities are calculated using the ISOSHLD (Appendix B) shielding program.

Programming Considerations

ONSITE/MAXI1 is written in FORTRAN-77 and versions are available which operate on VAX 11/780 (Kennedy et al. 1986), CDC 6600-7600 series (Napier et al. 1984), and IBM PC/XT/AT (Kennedy et al. 1987) computers.

Current Contact

Bruce Napier, K3-54
Battelle, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-375-3896

Sources

Kennedy, W. E., Jr., R. A. Peloquin, B. A. Napier, and S. M. Neuder. 1986. Intruder Dose Pathway Analysis for the Onsite Disposal of Radioactive Wastes: The ONSITE/MAXI1 Computer Program. NUREG/CR-3620 Supplement 1, U.S. Nuclear Regulatory Commission, Washington, D.C.

Kennedy, W. E., Jr., R. A. Peloquin, B. A. Napier, and S. M. Neuder. 1987. Intruder Dose Pathway Analysis for the Onsite Disposal of Radioactive Wastes: The ONSITE/MAXI1 Computer Program. NUREG/CR-3620 Supplement 2, U.S. Nuclear Regulatory Commission, Washington, D.C.

Napier, B. A., R. A. Peloquin, W. E. Kennedy, Jr., and S. M. Neuder. 1984. Intruder Dose Pathway Analysis for the Onsite Disposal of Radioactive Wastes: The ONSITE/MAXI1 Computer Program. NUREG/CR-3620, U.S. Nuclear Regulatory Commission, Washington, D.C.

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PABLM

PABLM calculates internal radiation doses to man from radionuclides in food products and external radiation doses from a range of environmental sources. Exposure pathway analyses include terms for radionuclides deposited on the ground or crops from contaminated air and irrigation water; radionuclides in contaminated drinking water and aquatic foods raised in contaminated water; and radionuclides in bodies of water and sediments where people might fish, boat, or swim.

A total of 19 ingestion pathways (or food products) may be selected with corresponding consumption rates, growing periods, and air or water concentrations and deposition rates. Up to four external exposure pathways may also be selected with corresponding exposure times and soil or water concentrations. The program is designed to calculate accumulated doses to 23 possible body organs or tissues for any one or combination of radionuclides (a maximum of five organs and 100 radionuclides per case is specified).

Doses may be calculated for either a maximally exposed individual or for a population group. The doses calculated are accumulated doses from continuous chronic exposure. A first-year committed dose is calculated as well as an integrated dose for a selected number of years.

Radioactive decay is considered during the release of radionuclides, after they are deposited on plants or on the ground, and during holdup of food after harvest. A chain decay scheme is used that includes branching to account for transitions to and from isomeric states.

The output from PABLM consists of radiation dose summaries for all chosen organs, listed by exposure pathway and by radionuclide. Dose summaries may be chosen for all terrestrial food pathways and all aquatic food pathways.

Assumptions and/or Limitations

The following assumptions have been incorporated in the PABLM program:

- The equations for calculating internal dose and dose commitment are derived from those given by the ICRP for body burdens and MPC of each radionuclide (ICRP 1959). Metabolic parameters for the Reference Man (ICRP 1975) are used.

- Usage parameters (i.e., duration of exposure to external sources of radiation and intake rates of ingested food and water) for the average adult are assumed in population dose calculations.

- Radiation doses from external exposure to contaminated water and soil are calculated by assuming that the contaminated medium is large enough to be considered an "infinite" volume or plane relative to the range of emitted radiations.

- Constant ingestion rates are assumed for food products.

- The concentrations of ^{3}H and ^{14}C in the carbon and hydrogen of environmental media (soil, plants, and animal products) are assumed to have the same specific activity as in the contaminating medium (air or water). The fractional content of carbon or hydrogen in a plant or animal product is then used to compute the concentration of ^{3}H or ^{14}C in the food product under consideration. The model assumes that plants obtain all of their carbon from irrigation water and that animals obtain all of their carbon from ingestion of plants.

- In predicting radionuclide concentrations in the sediments of a river or lake downstream from a nuclear facility, it is assumed that there is a constant water concentration for each year of the release and that deposition rate to the sediment is dependent only on water concentration.

- External doses from radionuclides deposited on farm fields are calculated assuming an infinite flat-plane source model.

Programming Considerations

PABLM is written in ASCII FORTRAN and operates on UNIVAC 1100/44 computers.

Current Contact

Bruce Napier, K3-54
Battelle, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-375-3896

Source

Napier, B. A., W. E. Kennedy, Jr., and J. K. Soldat. 1980. PABLM-A Computer Program to Calculate Accumulated Radiation Doses from Radionuclides in the Environment. PNL-3209, Pacific Northwest Laboratory, Richland, Washington.

SUBDOSA

SUBDOSA is used to calculate external radiation doses from the accidental atmospheric release of radionuclides. Dose calculations are based on the quantity of radionuclide released, duration of release, atmospheric conditions during release, and horizontal distance from the release point. Both gamma and beta radiation are calculated as a function of depth in tissue, summed and reported as skin, eye, gonadal, and total body dose. The dose from gamma radiation is calculated using a numerical integration technique to account for the finite size of the plume.

Doses are calculated for releases within each of several release time-intervals. Up to six time intervals can be specified and separate nuclide inventories and atmospheric dispersion conditions are considered for each time interval. Radioactive decay is considered during release and/or transit using a chain decay scheme that includes branching to account for transitions to and from isomeric states.

Output from SUBDOSA consists of the normalized air concentrations of radionuclides at ground level, and requested radiation doses listed as a function of distance from the point of release.

Assumptions and/or Limitations

The following assumptions have been incorporated in the SUBDOSA program:

- External dose calculations for the skin, lens of eye, and total body assume tissue depths of 0.007, 0.1 and 5 cm, respectively.
- Radionuclides deposited in the body via inhalation pathways are not considered.
- Diffusion along the direction of cloud travel is ignored.
- Vertical and lateral crosswind concentrations are normally distributed and the standard deviations are a function of atmospheric stability and distance from the release point. In some dispersion models, the standard deviations are wind-speed dependent.
- The dose receptor is at ground level.
- Cloud depletion by fallout, washout, and rainout can be described by a factor dependent on the distance of travel and is independent of travel time and displacement from the centerline.

- The contribution to dose from radionuclides greater than ± 800 m (from the exposure point) in the direction of cloud travel are ignored.

- Radionuclide decay is calculated for each radionuclide based on travel time to the exposure point, and this concentration is used for all downwind integration points about the exposure point.

Programming Considerations

SUBDOSA is written in FORTRAN-77 and versions are available which operate on UNIVAC 1100/44 and VAX 11/780 computers.

Current Contact

Dennis Strenge, K6-96
Battelle, Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352
509-376-2610

Source

Strenge, D. L., E. C. Watson and J. R. Houston. 1975. SUBDOSA-A Computer Program for Calculating External Doses from Accidental Atmospheric Releases of Radionuclides. BNWL-B-351, Pacific Northwest Laboratory, Richland, Washington.

6.0 STATUTORY AND REGULATORY REQUIREMENTS

The Hanford Site is owned by the U.S. Government and is managed by the U.S. Department of Energy (DOE). It is the policy of the DOE to carry out its operations in compliance with all applicable federal laws and regulations, state laws and regulations, presidential executive orders, and DOE orders. Environmental regulatory authority over the Hanford Site is vested both in federal agencies, primarily the U.S. Environmental Protection Agency (EPA), and in Washington State agencies, primarily the Washington Department of Ecology (Ecology). Significant environmental laws and regulations are discussed in this chapter. Federal laws and regulations are discussed first, followed by applicable state regulations. DOE orders, permits, and some specific regulations for the environmental protection of the public are then discussed.

[The following introduction (italicized text) is intended to be explanatory for persons writing a Chapter 6.0 for a Hanford Site EIS, but is not intended to be included in the EIS.]

INTRODUCTION

The regulations of the Council on Environmental Quality (CEQ) in the Code of Federal Regulations (CFR) at 40 CFR 1500-1508 implement the National Environmental Policy Act (NEPA) and set forth requirements for the preparation of environmental documentation by federal agencies. The CEQ regulations develop the NEPA process and focus on the environmental impact statement (EIS). The CEQ regulations 1) identify the types of actions proposed by a federal agency that require preparation of an EIS, 2) prescribe the content of an EIS, and 3) identify actions and other environmental reviews that must be undertaken by the federal agency in preparing and circulating an EIS. In general, an EIS must be prepared by a federal agency for any major federal action significantly affecting the quality of the human environment (40 CFR 1502.3).

A specific requirement in the CEQ regulations (40 CFR 1502.25) is that the EIS must list "all Federal permits, licenses, and other entitlements which must be obtained in implementing the proposal." There is, however, no requirement in the CEQ regulations that the EIS must list or discuss applicable environmental laws and regulations. Nevertheless, applicable environmental laws and regulations have been discussed in recent Hanford Site EISs, and Chapter 6.0 of these EISs has evolved into a chapter on "Statutory and Regulatory Requirements." Given the large number of applicable environmental regulations and the rapidly changing character of environmental regulation, this practice is likely to continue.

The purpose, then, of this document is to present a "reference" Chapter 6.0 that can be used in the preparation of future Hanford Site EISs. The intent here is to present a rather inclusive discussion of federal and state environmental laws, regulations, and permits that are applicable to activities at the Hanford Site. The information in this chapter can then be adapted to any future Hanford Site EIS simply by deleting the irrelevant parts and by adding some specificity with respect to the proposed action. It is also intended that this document be revised on a regular basis because of the rapidly changing character of federal environmental law and regulation, particularly because of the rapidly emerging (and thus still not fully developed) regulation of federal facilities by states.

It should be noted that environmental standards and permit requirements usually appear in regulations and not in the laws themselves. Thus, more emphasis is placed on regulations and less on laws in this document.

ORDER OF PRECEDENCE OF FEDERAL AND STATE ENVIRONMENTAL LAWS AND REGULATIONS

Environmental regulation of federal facilities is governed by federal law. Most major federal environmental laws now include provision for regulation of federal activities that impact the environment. The activity to be regulated is usually an activity being carried out by an agency of the executive branch. The environmental law will also designate a specific agency, such as the U.S. Environmental Protection Agency (EPA) or the U.S. Nuclear Regulatory Commission (NRC), as the regulator, or the law will permit self-

regulation. In addition, federal laws may provide for the delegation of the environmental regulation of federal facilities to the states or may directly authorize the environmental regulation of federal facilities by the states, through waivers of sovereign immunity. At Hanford, all these situations apply in varying degrees: the EPA has regulatory authority over Hanford facilities (where not authorized or delegated) and the NRC may have some future regulatory authority over some future Hanford facilities; the EPA shares regulatory authority with, or is in the process of delegating regulatory authority to, the State of Washington; and the State of Washington asserts its own independent regulatory authority under waivers of sovereign immunity.

As a practical matter at Hanford, federal and state environmental standards must be met. As a legal matter, differences in language between federal law and the pursuant state laws and regulations may result in some difference in applicability and interpretations. These prospective events, however, need not concern us here, and guidance on specific applicability should be obtained from Hanford Site legal counsel.

CITATION OF LAWS AND REGULATIONS

Laws and regulations may be cited both by their name and by their location in the appropriate reference. Federal laws are most often cited as a public law (Pub. L. or PL) or by their location in the United States Code (U.S.C. or USC). Section numbers differ between the two, so it must be understood which is being cited. Federal regulations appear in the CFR. Washington State laws are most often cited by their location in the Revised Code of Washington (RCW), and Washington State regulations are cited by their location in the Washington Administrative Code (WAC). Announcements of proposed and final federal regulations appear in the Federal Register (FR). Announcements of proposed and final Washington State regulations appear in the Washington State Register (WSR).

SPECIFIC FEDERAL LAWS CITED IN THE CEQ REGULATIONS

Four federal laws are specifically cited in the CEQ regulations and deserve mention here. These are Section 309 of the Clean Air Act

(42 U.S.C. 7609), the Fish and Wildlife Coordination Act (16 U.S.C. 661 et seq.), the National Historic Preservation Act (16 U.S.C. 470 et seq.), and the Endangered Species Act (16 U.S.C. 1531 et seq.). Section 309 of the Clean Air Act directs the EPA to review and comment on the environmental impacts of federal activities, including actions for which EISs are prepared. In addition to commenting, EPA rates every draft EIS prepared by a federal agency. EPA's comments are answered in the final EIS, but the EPA rating is usually not mentioned in an EIS. This latter fact should be known by the EIS preparers so that the EIS will be prepared in such a fashion as to avoid an unfavorable rating. The other three federal laws are often discussed in the chapter on the affected environment, rather than in the chapter on statutory and regulatory requirements. They should be discussed somewhere in the EIS and are discussed here for completeness.

6.1 FEDERAL ENVIRONMENTAL LAWS

Significant federal environmental laws applicable to the Hanford Site include the following:

- National Environmental Policy Act (NEPA) (42 U.S.C. 4321 et seq.)
- Clean Air Act (CAA) (42 U.S.C. 7401 et seq.)
- Clean Water Act (CWA) (33 U.S.C. 1251 et seq.)
- Safe Drinking Water Act (SDWA) (42 U.S.C. 300f et seq.)
- Resource Conservation and Recovery Act (RCRA) as amended by the Hazardous and Solid Waste Amendments (42 U.S.C. 6901 et seq.)
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) as amended by the Superfund Amendments and Reauthorization Act (SARA) (42 U.S.C. 9601 et seq.).

Other federal environmental laws applicable to the Hanford Site include the following:

- Endangered Species Act (16 U.S.C. 1531-1534)
- Fish and Wildlife Coordination Act (16 U.S.C. 661-666c)
- Bald and Golden Eagle Protection Act (16 U.S.C 668-668d)

- Migratory Bird Treaty Act (16 U.S.C 703-711)
- National Historic Preservation Act (16 U.S.C. 470-470w-6)
- Archaeological Resources Protection Act (16 U.S.C. 470aa-470ll)
- Archaeological and Historic Preservation Act (16 U.S.C. 469-469c)
- American Antiquities Act (16 U.S.C. 431-433)
- American Indian Religious Freedom Act (42 U.S.C. 1996).
- Comprehensive Conservation Study of the Hanford Reach of the Columbia River (PL 100-605).

In addition, the Atomic Energy Act (AEA) (42 U.S.C. 2011 et seq.), the Low-Level Radioactive Waste Policy Act (LLWPA) (42 U.S.C. 2021b et seq.), and the Nuclear Waste Policy Act (NWPA) (42 U.S.C. 10101 et seq.), while not environmental laws per se, contain provisions under which environmental regulations applicable to the Hanford Site may be or have been promulgated.

6.2 EPA REGULATIONS

EPA regulations that may apply to DOE operations at the Hanford Site have been promulgated under the NEPA, CAA, CWA, SDWA, RCRA, CERCLA, SARA, AEA, LLWPA, NWPA, and other federal statutes. Several of the more important of these regulations are listed below:

- 40 CFR 50, "National Primary and Secondary Ambient Air Quality Standards." EPA regulations in 40 CFR 50 set national ambient air quality standards for air pollutants including sulfur oxides, particulate matter, carbon monoxide, ozone, nitrogen dioxide, and lead.
- 40 CFR 60, "Standards of Performance for New Stationary Sources." EPA regulations in 40 CFR 60 provide standards for the control of the emission of pollutants to the atmosphere. Construction or modification of an emissions source may require a prevention of significant deterioration of air quality (PSD) permit under 40 CFR 52. Pollutants include those identified in the preceding paragraph and radionuclides.
- 40 CFR 61, "National Emission Standards for Hazardous Air Pollutants," (NESHAP); also 40 CFR 61 Subpart H, "National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities." EPA hazardous emission standards

in 40 CFR 61 provide for the control of the emission of hazardous pollutants to the atmosphere, and standards in 40 CFR 61 Subpart H apply specifically to the emission of radionuclides from DOE facilities. Approval to construct a new facility or to modify an existing one may be required by these regulations.

- 40 CFR 122, "The National Pollutant Discharge Elimination System" (NPDES). EPA regulations in 40 CFR 122 (and also in 40 CFR 125 and 129) apply to the discharge of pollutants from any point source into waters of the United States. NPDES permits may be required by 40 CFR 122.

- 40 CFR 141, "National Primary Drinking Water Regulations." EPA drinking water standards in 40 CFR 141 apply to Columbia River water at community water supply intakes downstream of the Hanford Site.

- 40 CFR 144-147, "Underground Injection Control Program" (UIC). EPA regulations in 40 CFR 144-147 apply to the underground injection of liquids and wastes and may require a permit for any underground injection. In Washington State, the WAC-173-218 UIC program operates in lieu of this EPA program.

- 40 CFR 191, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes." EPA regulations in 40 CFR 191 provide environmental standards for the management, storage, and disposal of spent nuclear fuel, high-level radioactive wastes, and transuranic radioactive wastes at high-level transuranic waste disposal sites. EPA continues to work on a revision to subpart B of those regulations, which were remanded by the courts for EPA's reconsideration.

- 40 CFR 193 (to be issued), "Environmental Radiation Protection Standards for Management and Land Disposal of Low-Level Radioactive Wastes." EPA environmental radiation protection standards for low-level radioactive waste disposal in 40 CFR 193 will apply, when promulgated by the EPA, to the disposal of low-level radioactive waste owned by DOE. At present, however, only an advance notice of proposed rule making has been published by the EPA, and no draft standards are available for public review.

- 40 CFR 260-268 and 270-272, "Hazardous Waste Management." EPA RCRA regulations in 40 CFR 260-268 and 270-272 apply to the treatment, transport, storage, and disposal of hazardous wastes (but not to source, by-product, or special nuclear material, i.e., not in general to radioactive wastes) and apply to the hazardous component of hazardous radioactive-mixed wastes (but not to the radioactive component) owned by DOE. RCRA permits may be required by these regulations.

- 40 CFR 280-281, Underground Storage Tanks. EPA regulations in 40 CFR 280-281 apply to underground storage tanks and may require permits for new and existing tanks. EPA may authorize state regulation of underground storage tanks.

- 40 CFR 300, "National Oil and Hazardous Substances Pollution Contingency Plan." EPA CERCLA regulations in 40 CFR 300 apply to the cleanup of inactive hazardous waste disposal sites and to the cleanup of hazardous substances released into the environment. On November 3, 1989, the Hanford Site was placed on the EPA's National Priorities List (NPL). Placement on the list requires DOE, in consultation with EPA and Washington State, to conduct remedial investigations and feasibility studies leading to a record of decision on the cleanup of the retired facilities at Hanford. In anticipation of Hanford's being placed on the NPL, DOE, EPA, and WDOE signed the Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) on May 15, 1989. This agreement describes the cleanup responsibilities and authorities of the three parties under CERCLA (and RCRA), and also provides for permitting of the treatment, storage, and disposal of hazardous wastes under RCRA.

6.3 <u>OTHER FEDERAL REGULATIONS</u>

- 10 CFR 1021, "Compliance with the National Environmental Policy Act." DOE regulations in 40 CFR 1021 implement the National Environmental Policy Act (NEPA) and the Council on Environmental Quality's NEPA regulations in 40 CFR 1500-1508.

- 10 CFR 1022, "Compliance with Floodplain/Wetlands Environmental Review Requirements." DOE regulations in 10 CFR 1022 apply to DOE activities that are proposed to take place either in wetlands or in floodplains.

- 33 CFR 322-323, 40 CFR 230-233, Corps of Engineers Permits. Structures in the Columbia River and work in the Columbia River, as well as the discharge of dredged or fill material into the Columbia River, require Corps of Engineers permits under these regulations.

- 36 CFR 800, 25 CFR 261, 43 CFR 3, and 43 CFR 7, historic preservation regulations. Requirements of the National Historic Preservation Act in 36 CFR 800, the American Antiquities Act in 25 CFR 261 and 43 CFR 3, and the Archaeological Resources Protection Act and the American Indian Religious Freedom Act in 43 CFR 7 apply to the protection of historic and cultural properties, including both existing properties and those discovered during excavation and construction.

- 40 CFR 1500-1508, Regulations of the Council on Environmental Quality (CEQ) that implement NEPA. The CEQ regulations in 40 CFR 1500-1508 provide for the preparation of environmental documentation on any federal action impacting the environment, and require federal agencies to prepare an environmental impact statement (EIS) on any major federal action significantly affecting the quality of the human environment.

- 49 CFR 171-179, "Hazardous Materials Regulations." Department of Transportation regulations in 49 CFR 171-179 apply to the handling, packaging, labeling, and shipment of hazardous materials offsite, including radioactive materials and wastes.

- 50 CFR 10-24 and 50 CFR 402, species protection regulations. Regulations of the Endangered Species Act, the Bald and Golden Eagle Protection Act, and the Migratory Bird Treaty Act in 50 CFR 10-24 and 50 CFR 402 apply to the protection of these species on the Hanford Site.

6.4 STATE REGULATIONS

Activities of the federal government are ordinarily not subject to regulation by the states, unless specific exceptions are created by Congress. Exceptions with respect to environmental regulation have been created by Congress and provisions in several federal laws give to the states specific authority to regulate federal environmental activities. These waivers (or partial waivers) of sovereign immunity appear in Section 118 of the CAA, Section 313 of the CWA, Section 1447 of the SDWA, Section 6001 of RCRA, and Section 120 of CERCLA/SARA. At the present time, most Washington State programs with respect to the environmental regulation of Hanford facilities are coordinated with EPA Region 10.

Washington State regulations potentially applicable to the environmental regulation of federal activities at Hanford are listed below.

- WAC 173-218, "Underground Injection Control Program." Ecology regulations in WAC 173-218 provide standards and permit requirements for disposal of fluids by well injection. The Ecology regulations have been approved by the EPA to operate in lieu of the EPA UIC program.

- WAC 173-303, "Dangerous Waste Regulations." The EPA has authorized the State of Washington through the Ecology to conduct its own dangerous waste regulation program in lieu of major portions of the RCRA interim and final permit program for the treatment, storage, and disposal of hazardous wastes. Ecology is also authorized to conduct its own program for the hazardous portion of radioactive-mixed wastes. However, EPA has retained its authority to administer those sections of the hazardous waste program mandated by the Hazardous and Solid Waste Amendments to RCRA. The state regulations include both standards and permit requirements.

- WAC 173-400 through 173-495, Washington State Air Pollution Control Regulations; General Regulation 80-7, Benton-Franklin-Walla Walla Counties Air Pollution Control Authority. Ecology air pollution control regulations, promulgated under the Washington Clean Air Act, appear in WAC 173-400 through 173-495. These regulations include both emission standards and ambient air quality standards. The State of Washington has delegated most of its authority under the Washington Clean Air Act to the Benton-Franklin-Walla Walla Counties Air Pollution Control Authority. General Regulation 80-7 contains emission standards and authorization requirements for nonradioactive air pollutants.

- WAC 402-80, "Monitoring and Enforcement of Air Quality and Emission Standards for Radionuclides." Washington Department of Health regulations in WAC 402-80 contain standards and permit requirements for the emission of radionuclides to the atmosphere from DOE facilities based on Ecology standards in WAC 173-480, "Ambient Air Quality Standards and Emission Limits for Radionuclides."

6.5 DOE ORDERS

The most significant DOE orders with respect to environmental compliance at Hanford are the 5400 and 5480 series, beginning with DOE Order 5400.1, "General Environmental Protection Program," and DOE Order 5480.1B, "Environment, Safety, and Health Program for Department of Energy Operations." These orders cover environmental protection, safety, and health protection standards; hazardous and radioactive-mixed waste management; cleanup of retired facilities; safety requirements for the packaging and transportation of hazardous materials; safety of nuclear facilities; radiation protection; and other standards for the safety and protection of workers and the public. Regulations and standards of other federal agencies and regulatory bodies, as well as other DOE orders, are incorporated by reference into DOE orders.

Other DOE orders that are important with respect to environmental compliance include DOE Order 5820.2A, "Radioactive Waste Management."

6.6 PERMITS

The DOE holds a NPDES permit from EPA Region 10 for the discharge of nonradioactive liquids to the Columbia River. On June 28, 1985, the DOE applied for renewal of this permit. The original permit is still in effect pending renewal.

The DOE holds a PSD permit from EPA Region 10 for the discharge of oxides of nitrogen to the atmosphere from the PUREX and Uranium Oxide Plants.

The DOE holds approvals for construction of air emission facilities and approvals of alternate air emission limits issued by the Benton-Franklin-Walla Walla Counties Air Pollution Control Authority.

The DOE received a NESHAP authorization on November 28, 1986, from EPA Region 10 for construction of the transportable grout facility.

The DOE received a Radioactive Source Registration permit from the Washington Department of Health on August 15, 1989, for radioactive emissions from Hanford Site operations.

The DOE holds interim status for the operation of hazardous waste management facilities by virtue of having submitted a RCRA Part A application to EPA on November 18, 1980. On November 6, 1985, the DOE submitted a RCRA Part B application to EPA Region 10 and to the WDOE for the storage, treatment, and disposal of hazardous wastes at Hanford. Supplemented and revised RCRA applications have been submitted either to Ecology, to the EPA, or to both as appropriate.

DOE has asserted a federally reserved water withdrawal right with respect to its Hanford operations. Nevertheless, DOE submitted an application to the Washington State Department of Ecology (Ecology) on July 7, 1987, as a matter of comity for water withdrawal rights from the Columbia River for site characterization activities related to the Basalt Waste Isolation Project. On October 23, 1987, WDOE granted a temporary permit to DOE. Current activities only utilize water withdrawn under the Department's federally reserved water right.

6.7 ENVIRONMENTAL STANDARDS FOR PROTECTION OF THE PUBLIC

Numerical standards for protection of the public from releases to the environment have been set by the EPA and appear in 40 CFR 61 and 40 CFR 141. The standards in 40 CFR 61.92 apply to releases of radionuclides to the atmosphere from DOE facilities and state that:

> Emissions of radionuclides [other than radon-220 and radon-222] to the ambient air from Department of Energy facilities shall not exceed those amounts that would cause any member of the public to receive in any year an effective dose equivalent of 10 mrem/yr.

The standards in 40 CFR 141.16 apply indirectly to releases of radionuclides from DOE facilities (and also non-DOE facilities) to the extent that the releases impact community water systems:

> The average annual concentration of beta particle and photon radioactivity from man-made radionuclides in drinking water shall not produce an annual dose equivalent to the body or any internal organ greater than 4 millirem/year.

Also, maximum contaminant levels in community water systems of 5 picocuries per liter of combined radium-226 and radium-228, and maximum contaminant levels of 15 picocuries per liter of gross alpha particle activity, including radium-226 but excluding radon and uranium, are specified in 40 CFR 141.

40 CFR 141 also specifies maximum concentrations of some chemical contaminants in drinking water.

EPA regulations in 40 CFR 193, "Environmental Radiation Protection Standards for Management and Land Disposal of Low-Level Radioactive Wastes," when promulgated, will contain numerical standards for protection of the public from releases of radioactivity from low-level radioactive waste management and disposal activities.

EPA regulations in 40 CFR 264 contain numerical standards for protection of the public from releases of hazardous wastes from hazardous waste disposal sites.

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